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THE EFFECTS OF WEARING PROTECTIVE CHEMICAL WARFARE COMBAT CLOTHING ON HUMAN PERFORMANCE

Henry L. Taylor
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August 1991

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U.S. Department of Defense studies to measure performance decrements associated with wearing chemical warfare (CW) protective combat clothing indicate that heat stress produced seriously degraded human performance. Even when heat stress is not a significant factor, performance of many combat, combat support, and combat service support tasks is degraded. In most field studies, many crews of combat units became operationally ineffective due to voluntary withdrawal of individual crew members. Many combined arms, field studies, and laboratory studies indicate that when CW-protective combat clothing is worn performance is seriously degraded for (1) the detection of targets, engagement time, accuracy of fire, and (2) manual dexterity tasks; and that (3) a variety of psychological effects are created. Further, the degree of performance degradation varied with the tasks performed. Training in CW-protective combat clothing permits learning to modify procedures and consequently reduce negative effects, provided heat stress is not a significant factor. A growing body of evidence indicates there is inadequate training in the use of CW-protective combat clothing. A critical need exists for more and better training of skills needed under CW conditions.

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ABSTRACT

U.S. Department of Defense studies to measure performance decrements associated with wearing chemical warfare (CW) protective combat clothing indicate that heat stress seriously degraded human performance. Even when heat stress is not a significant factor, performance of many combat, combat support, and combat service support tasks is degraded. In most field studies, many crews of combat units became operationally ineffective due to voluntary withdrawal of individual crew members. Many combined arms, field studies, and laboratory studies indicate that when CW-protective combat clothing is worn performance is seriously degraded for (1) the detection of targets, engagement time, accuracy of fire, and (2) manual dexterity tasks; and that (3) a variety of psychological effects are created. Further, the degree of performance degradation varied with the tasks performed. Training in CW-protective combat clothing permits learning to modify procedures and consequently reduce negative effects, provided heat stress is not a significant factor. A growing body of evidence indicates there is inadequate training in the use of CW-protective combat clothing. A critical need exists for more and better training of skills needed under CW conditions.

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ABBREVIATIONS

AGE	Aerospace Ground Equipment
AHSG108	Ad Hoc Study Group 108
AIT	Advanced Individual Training
ANOVA	Analysis of Variance
APC	Armored Personnel Carrier
BDO	Battle Dress Overgarment
BDU	Battle Dress Uniform
BIFV	Bradley Infantry Fighting Vehicle
BMP	Soviet Infantry Vehicle
CANE	Combined Arms in a Nuclear/Chemical Environment
CAS	Crew Atmospheric Scale
CB	Chemical, Biological
CBR	Chemical, Biological, and Radiological
CIC	Command Information Center
CMS	Clyde Mood Scale
CP	Command Post
CPO	Chemical Protective Overgarment
CS	Riot Control Agent
CSQ	Cognitive Strategies Questionnaire
CVC	Combat Vehicle Crewman
CW	Chemical Warfare
CWD	Chemical Warfare, Defense

D_A	Percent Accuracy Degradation
D_T	Percent Time Degradation
ESQ	Environmental Symptoms Questionnaire
FDC	Fire Direction Center
FIST	Fire Support Team
FTD	Field Training Detachment
FTX	Field Training Exercise
GLLD	Ground Laser Locator Designator
HAAT	Heading, Altitude, Airspeed and Time
HUMAN	Human Utilization Model and Analytic Network
IRON MAN	Armor Field Trial
KCAL	Kilocalories
LKA	Amphibious Cargo Ship
LPD	Amphibious Transport Dock
LST	Tank Landing Ship
M_g	Milligram
MILES	Multiple Integrated Laser Engagement System
MOPP	Mission-Oriented Protective Posture
MOS	Military Occupational Specialty
NBC	Nuclear, Biological and Chemical
NOE	Nap-of-the-Earth
NOMEX	Synthetic Tanker or Flightsuit with Fire Retardant Capabilities
PAB	Walter Reed Performance Assessment Battery
P^2NBC^2	Psychological and Physiological Effects of NBC and Extended Operations
PMCS	Preventive Maintenance Checks and Services

Rh	Relative Humidity
RMS	Root Mean Square Error
SAI	State Anxiety Inventory
SIMNET	Networked Simulation
SMEs	Subject Matter Experts
TCT	Tactical Computer Terminal
TOC	Tactical Operations Center
TOW	Tube Launched, Optically Tracked, Wire-Guided Missile
TRI-TAC	Joint Tactical Communications Program
TTCP	The Technical Cooperation Program
UK	United Kingdom
UPI	USARIEM Performance Inventory
USAFSAM	U.S. Air Force School of Aviation Medicine
USARIEM	U.S. Army Research Institute for Environmental Medicine
WBGT	Wet Bulb Globe Temperature
Yca	Numbers of Hits, Errors, etc., by Control Group
Yct	Time for a Control Group to Complete Task
Yxa	Number of Hits, Errors, etc., by an Experimental Group Wearing CW-Protective Combat Clothing
Yxt	Time for an Experimental Group Wearing CW-Protective Combat Clothing to Complete a Task

EXECUTIVE SUMMARY

This paper is a critical review of studies completed since 1979 that examine the effects of wearing chemical warfare (CW) protective combat clothing on individual and unit performance. Both experimental and operational studies are covered. The methodology used to determine performance decrements is critiqued, and the extent to which training or changes in procedures can reduce the decrements caused by wearing the CW-protective combat clothing is assessed.

Since the early 1980s, the U.S. Department of Defense has sponsored a number of major projects designed to determine performance decrements resulting from wearing CW protective combat clothing. These efforts fall into three major categories: (1) combined arms exercises, (2) field trials, and (3) laboratory studies. Studies reviewed and critiqued in the present report are organized in these categories. Four appendixes summarize aspects of performance degradation.

Combined arms exercises are conducted to provide quantitative information and realistic combat experience for combat, combat support, and combat service support units. The review of combined arms exercises in a nuclear/chemical environment, which simulates an integrated battlefield, was important to determine the effectiveness with which a combined arms force can accomplish its mission under chemical warfare combat conditions. Such exercises generally use an instrumented battlefield and are conducted over a sustained period of time. These are exercises that use a trained opposing force, have a defined and previously tested realistic combat scenario, generally provide both objective and subjective data, and are supervised by judges and controllers. The most effective exercises compare a baseline condition with an "exercise" condition that includes parameters of interest. The parameter of interest for this paper is simulated chemical combat threat conditions.

Combined arms exercises provide data that can be most readily generalized to a combat situation but, in general, are less likely to be as tightly controlled as field studies and are substantially less well controlled than laboratory studies. Variables used in combined arms exercises are also often tested in field and laboratory studies prior to their use in combined arms exercises.

Field trials are generally more narrowly defined and more tightly controlled than combined arms exercises, but are less so than laboratory studies. Field trials often include only one combat, combat support, or combat service support unit. The most recent field trials reviewed in this paper have been conducted for periods of 24-72 hours to provide data concerning sustained operations in a chemical warfare combat environment.

Laboratory studies generally provide the greatest degree of experimental control and investigate more narrowly defined parameters but are less useful in generalizing to unit performance.

The review and critique of studies in all three categories supported the following conclusions.

1. Heat stress, due to wearing CW-protective combat clothing, seriously degrades human performance. This finding is supported by many studies reviewed in this paper and in previous papers by Taylor and Orlansky (1986, 1987). Under some conditions, performance will degrade significantly within one hour. Endurance can be extended, if ambient workplace temperatures are not severe, by enforced drinking of water and by frequent rest periods. Heat stress effects have been modeled by Goldman and associates at the U.S. Army Research Institute for Environmental Medicine (USARIEM). The USARIEM heat stress model accurately predicts (± 10%) the human metobolic heat production of soldiers when the level of encapsulation, environment, physical condition of troops, combat mission (including duration), physical activity, and work/rest cycles can be accurately specified.
2. Even when heat stress is not a significant factor, the performance of many combat and combat support tasks in all combat arms is degraded when CW-protective combat clothing is worn. This degradation is due to reduced manual dexterity, reduced vision, reduced ability to communicate, respiratory stress, and psychological stress. This finding is supported by a number of studies reviewed in the present paper as well as in previous reviews by Taylor and Orlansky (1986, 1987).
3. Studies on endurance of combat crews in armor, mechanized infantry, artillery, and aviation operating in CW-protective combat clothing and involved in continuous operations have indicated that crews will have difficulty sustaining effective combat operations even when heat exhaustion is not a significant factor. In most studies, many crews of combat units have become operationally ineffective due to voluntary withdrawal of individual crew members from the test.

4. During a combined arms exercise, the duration of battle was increased 82 percent and the loss-exchange ratio (killed attackers/killed defenders) was increased by 66 percent, from 2.40 in the baseline to 3.99 in the CW environment. This loss-exchange ratio is unacceptable according to current Army doctrine.

5. The detection of targets, the engagement times, and the accuracy of fire are significantly degraded when CW-protective combat clothing is worn. This finding is substantiated by a number of studies reviewed in this paper including combined arms exercises and continuous operations field trials. In a number of studies involving armor crews, increased target engagement times are a linear function of time of operations in CW-protective combat clothing.

6. Command and control, and communications are significantly degraded by wearing CW-protective combat clothing. This finding has been substantiated in recent combined arms exercises.

7. Wearing CW-protective combat clothing results in a significant and important increase in serious dehydration. During hot conditions, dehydration will occur within 1 hour or less when the individuals are engaged in physical activity, so enforced drinking is mandatory for health maintenance.

8. Manual dexterity tasks requiring both gross and fine motor skills are significantly degraded by wearing CW-protective combat clothing (masks and gloves). This finding is substantiated by studies involving the disassembly/assembly of small arms and a substantial number of maintenance tasks. The use of 7-mil or 14-mil gloves instead of the standard 22-mil glove provides better tactility and finger dexterity, but these thinner gloves appear to be more prone to compromise.

9. Wearing CW-protective combat clothing produces a variety of psychological effects including increased symptom intensity and general deterioration of mood. These findings are supported by a number of laboratory and field studies.

10. Recent laboratory studies suggest differences in physiological tolerance to heat stress between males and females, with female tolerance being lower, but this finding has not been established incontrovertably.

11. The studies reviewed previously (Taylor and Orlansky, 1987) and in the current paper clearly indicate that the amount of performance degradation due to wearing CW-protective combat clothing varies widely with the combat, combat support, or combat service support task to be performed. A general finding, however, is that wearing CW-protective combat clothing leads to a significant performance degradation of individual and unit performance.

12. With training in CW-protective combat clothing, individuals and crews will learn to modify procedures and consequently reduce the negative effects of wearing CW-protective combat clothing when heat stress is not a significant factor. A number of studies has indicated that training in CW-protective combat clothing can reduce the amount of performance decrement of individuals and crews performing combat, combat support and combat service support tasks.

13. In a simulated CW-combined arms exercise, the amount of prior CW-defense training of the platoon leader was an important variable affecting overall platoon performance, even when other platoon members had little CW-defense training.

14. Many studies reviewed in this and previous papers (Taylor and Orlansky, 1986, 1987) have emphasized the need for increased training in the use of CW-protective combat clothing. Only one study of the 21 reviewed by Taylor and Orlansky (1987) was designed to quantify the benefits of training under simulated CW conditions.

15. An objective of a number of field studies reviewed in the present paper was to determine the impact of training in CW-protective combat clothing on reducing performance decrements caused by wearing this clothing. These studies failed to achieve this objective since none established stable baseline performance in the battle dress uniform (BDU) prior to determining performance decrements due to wearing CW-protective combat clothing.

16. For a number of studies reviewed, meaningful comparisons between the BDU and CW-protective combat clothing could not be made due to the lack of data, an insufficient number of subjects, or poor experimental design.

17. A growing body of evidence indicates that there is *inadequate* training in the use of CW-protective combat clothing. This is supported by a review by Knapp and Orlansky (1987) and a Navy survey conducted by Moskal, Driskell and Carson (1987). The latter report concludes that a critical need exists for more and better training of CW common skills, i.e., the skills that all personnel need to know to protect themselves under CW conditions.

18. The growing availability of networked simulators, such as SIMNET, provides an opportunity to conduct battalion-level, two-sided engagements under experimental conditions. Thus, it now becomes possible to collect reliable data on performance in simulated, combat arms exercises, wearing CW-protective combat clothing, that can significantly extend what is now known reliably only in laboratory studies. Since networked simulation provides such data as weapons killed and exchange ratios used in most combat models, one should be able to estimate more precisely the military value (and/or penalty)

attributable to wearing CW-protective combat clothing and of training to achieve maximum benefit of its use.

Based on these findings four recommendations are made:

1. In 1987, Taylor and Orlansky found that "only one study, the Grand Plot III field trial, was designed to measure the amount of performance improvement due to training," and "recommended that future studies and field trials directly investigate the benefits of training. It is important to develop a more extensive documentation of the effects of training on mission effectiveness in simulated CW environments" (Taylor and Orlansky, 1987, pp. V-1). While a number of recent studies have had as an objective to determine the effects of training on improving individual and crew effectiveness in CW environments, methodological problems have limited the effectiveness of these studies. Consequently, this recommendation remains valid.

2. For studies designed to determine the effects of training on improving individual and crew effectiveness in CW environments, the individuals and crews should be well trained in the tasks to be performed. A stable baseline in battle dress uniform should be established prior to the introduction of CW-protective combat clothing (MOPP 4). Enough subjects should be used or trials conducted to permit statistical comparisons between baseline and experimental conditions, and to permit inferential statistics with enough "power" to enable the results to be used with confidence. After introducing the experimental conditions, enough trials should be conducted in CW-protective combat clothing to determine the effect of training in MOPP 4.

3. Performance decrements due to severe conditions are unavoidable but their impact can be delayed as well as reduced by appropriate training. The Desert Storm experience, not examined in this study, can provide important data on the performance of troops wearing CW-protective combat clothing on their arrival in theatre and the effect of training in improving their performance. We strongly urge that the lessons learned there about the effect of wearing CW-protective combat clothing and the effectiveness of training in its use be carefully reviewed.

4. The experimental data comparing male and female differences in performance to heat stress while wearing CW-protective combat clothing are extremely limited. In view of the increased numbers of females involved in combat support and combat service support roles, and the potential for females to be involved in combat situations in which a substantial CW threat exists, this area warrants increased research emphasis.

I. INTRODUCTION

A. OBJECTIVE

The objectives of this paper are to:

1. Critically review recent studies (since 1979) which investigated the effects of wearing CW-protective combat clothing on individual and unit performance.
2. Evaluate the methodology used to determine performance decrements.
3. Assess the extent to which training or procedural changes can reduce the decrements caused by wearing CW-protective combat clothing.

B. BACKGROUND

In a previous paper, Taylor and Orlansky (1986) reviewed and summarized a series of studies performed in Australia, Canada, New Zealand, the United Kingdom, and the United States, the member countries of The Technical Cooperation Program (TTCP), that show the effects on human performance of wearing protective clothing for CW (Taylor and Orlansky, 1986). In a second paper, data from these studies indicating that training can help avoid some degradation of performance were discussed (Taylor and Orlansky, 1987). These two review papers were generally limited to reports provided by members of the TTCP Ad Hoc Study Group 108 (AHSG 108), which met the following criteria: report sufficiently complete to permit replication, protective clothing approaching current capabilities, a clear description of the conditions of observation (e.g., agent, environment, protective clothing and equipment, duration of exposure, subjects, and measures); a few other reports that met these criteria were also included. However, the two reports were not a comprehensive review of all recent studies concerned with the effects on human performance of wearing CW-protective combat clothing.

The following conclusions were reached by Taylor and Orlansky (1987):

- Wearing CW-protective combat clothing produces heat stress effects that degrade physical human performance. This finding is supported by many studies. A computer model developed by Goldman accurately predicts physiological limits of combat troops when level of encapsulation, environment, physical condition of troops, combat

> mission (including duration), physical activity and work/rest cycles, can be accurately specified. Under some conditions, performance will degrade significantly within one hour. Endurance can be extended, if ambient work-place temperature conditions are not severe, by enforced drinking of water and by frequent rest periods.
>
> - Wearing CW-protective combat clothing during hot conditions is expected to produce dehydration within one hour or less. Enforced drinking of water is mandatory in order to prevent the effects of dehydration.
> - Wearing CW-protective combat clothing degrades performance across a variety of combat tasks for all combat arms as a function of reduced manual dexterity, restricted vision, restricted communication, and respiratory stress, even when heat stress is not a significant factor.
> - Detection of targets and the accuracy of fire are significantly degraded when protective masks are worn.
> - Communication is degraded by CW-protective combat clothing, but the magnitude of the effect has not been adequately documented.
> - Manual dexterity tasks such as disassembly/assembly of an M-16 rifle are significantly degraded by reduced vision due to masks and constraints caused by gloves.
> - Individuals and crews can be trained to modify procedures and thereby reduce the problems caused by wearing CW-protective combat clothing when heat stress is not a significant factor. Training to modify procedures can restore most but not all of the performance effectiveness otherwise lost.
> - Training increases proficiency on CW-defensive tasks. For some tasks, the knowledge and skill needed to cope with CW-protective combat clothing can be obtained during a brief training period. One study found that as little as two days' training significantly improved performance.
> - The studies reviewed clearly indicated that the amount of performance degradation due to CW-protective combat clothing varies widely with the tasks to be performed.
> - Only one study of the 21 reviewed was designed to quantify the benefits of training under simulated chemical warfare conditions.
>
> --Taylor and Orlansky, 1987, pp. IV-1 and IV-2

Current basic CW ensembles consist of an overgarment, hood, gloves, boots, and mask. The U.S. Army uses the Mission-Oriented Protective Posture (MOPP), which is a flexible procedure intended to guide the commander in the protection of troops in a chemical environment while facilitating mission accomplishment. It requires "individual

protective equipment consistent with the chemical threat, the workrate imposed by the mission and the temperature" (FM 21-40, 1977). Table I-1 describes four levels of CW-protective combat clothing.

Table I-1. United States Army Mission-Oriented Protective Posture (MOPP)

MOPP	Overgarment	Overboots	Mask/Hood	Gloves
Baseline Combat Uniform	Not worn	Not worn	Not worn	Not worn
1	Worn, open or closed based on temperature	Carried	Carried	Carried
2	Worn, open or closed based on temperature	Worn	Carried	Carried
3	Worn, open or closed based on temperature	Worn	Worn, hood open or closed based on temperature	Carried
4	Worn, closed	Worn	Worn, closed	Worn

The United States Air Force uses the same four levels of MOPP to describe CW-protective combat clothing but provides additional guidance to commanders (AFR 355-8, 1 May, 1987). Table I-2 shows the U.S. Air Force Mission-Oriented Protective Posture Summary. It also provides guidance concerning the MOPP conditions associated with the alarms and the potential variations for the various MOPP conditions.

Table I-2. United States Air Force Mission-Oriented Protective Posture (MOPP) Summary

<table>
<tr><th>MOPP</th><th>Used in Alarm</th><th>Over-Garment is</th><th>Over-Boots are</th><th>Masks and Hood are</th><th>Gloves and Inserts are</th><th>Other CW Individual Protective Equipment is</th><th>Field Gear is</th><th>Variations are</th></tr>
<tr><td>0</td><td>All Clear</td><td colspan="6">Readily Available</td><td>N/A</td></tr>
<tr><td>1</td><td>Yellow</td><td>Worn</td><td colspan="5">At Hand</td><td>Fatigue
Ventilate
Indoor</td></tr>
<tr><td>2</td><td>Yellow</td><td colspan="2">Worn</td><td colspan="4">At Hand</td><td>Fatigue
Ventilate
Indoor</td></tr>
<tr><td>3</td><td>Black</td><td colspan="3">Worn</td><td colspan="2">At Hand</td><td>Worn</td><td>Fatigue
Ventilate
Indoor</td></tr>
<tr><td>4</td><td>Red</td><td colspan="4">Worn</td><td>At Hand</td><td>Worn</td><td>Fatigue
Indoor</td></tr>
<tr><td>5</td><td>Black</td><td colspan="4">Worn</td><td>At Hand</td><td>Worn</td><td>Fatigue
Ventilate
Indoor</td></tr>
</table>

Wearing CW-protective combat clothing can degrade the performance of individuals and can reduce the performance effectiveness of a combat unit. The primary causes of such performance degradation are:

> - Heat stress due principally to the weight, insulation, and low moisture vapor permeability of the overgarment.
> - Reduced manual dexterity due to the constraints imposed by the gloves, overgarment, and boots.
> - Restricted vision due to the design and optical characteristics of the mask, e.g., reduced field-of-view and poor optical quality of the mask faceplate.
> - Restricted communication (hearing and speaking) due to the mask and hood.
> - Respiratory stress due to air resistance of mask filters and outlet valves.
>
> --Taylor and Orlansky, 1987, pp. I-1 and I-2

Of the above, the most extensive factor investigated has been heat stress or the thermoregulatory load imposed by CW-protective combat clothing in certain hot environments and/or by physical exertion. Studies conducted by the U.S. Army Research Institute for Environmental Medicine (USARIEM) and the United States Air Force School of Aerospace Medicine (USAFSAM) have documented the effects of heat stress (Goldman, 1974; Goldman, 1979; Goldman and Staff, 1981; Goldman and Staff, 1982; Pandoff and Goldman, 1978; Nunneley, 1987; Nunneley, 1989).

The inability to evaporate sweat while encapsulated in CW-protective combat clothing produces heat stress. Rectal temperature is a good indicator of the tolerance limit of soldiers while wearing CW-protective combat clothing and is related to the degree of risk of heat exhaustion. A rectal temperature of 39.2°C (102.5°F) equates to a 25 percent risk of heat exhaustion (Goldman and Staff, 1982). Pandolf and Goldman (1978) have stated that the convergence of skin temperature and rectal temperature is the best physiological guide to heat stress tolerance. Nunneley, Antunano, and Bromalosky (1990) have reported that studies in their laboratory provide no support that skin-core temperature convergence accurately predicts heat stress tolerance. Nunneley (1987) indicated that a rectal temperature of 39.5°C is often used for heat stress studies in the laboratory. Studies reviewed in the present paper have used a rectal temperature of 39.2°C while a subject is resting or a rectal temperature of 39.5°C (103°F) while exercising as the criterion to remove a volunteer from a test. Testing has also been discontinued if the subject's heart rate

exceeded 180 beats per minute for 5 minutes continuously during exercise or 160 beats per minute while resting (Glumm, 1988). These indices have proven to be useful for laboratory and field studies. Cadarette (1991) indicated that heat stress also occurs under conditions of increased rate of heat storage which is exacerbated by CW-protective combat clothing and can result in heat stress casualties at relatively low rectal remperatures and heart rates.

A computer model has been developed to predict heat stress effects (Goldman, 1974). A more recent version of the model is described by Pandolf, Stroschein, Drolet, Gonzales, and Swaka (1986). Given data concerning the level of the CW-protective combat clothing, the environment, the physical condition of the soldiers, and the proposed mission, the model can specify the physiological limit of combat personnel operating under a CW scenario. Gonzalez and Stroschein (1991) indicate that the model is most effective in forecasting work/rest cycles, water requirements and tolerance times in the heat with CW-protective combat clothing since the databases and regression analysis are concentrated in these areas. Goldman (1974) states the model's prediction of human metabolic heat production has been validated by data collected in both laboratory and field trials across a range of military populations and has been found to be accurate to ± 10% which is comparable to the precision of the measurement of heat stress in field trials. Goldman (1979) has indicated the following uses of the model: (1) to prevent heat stress casualties; (2) to establish work/rest cycles while wearing CW-protective combat clothing; (3) to permit trade-off analyses during the development of CW-protective combat clothing; (4) to predict whether a planned study will provide useful data, i.e., whether the conditions will produce measurable physiological differences but not impose undue risk on the subjects. The Goldman model of heat stress and several other thermal models were evaluated in a workshop (Wissler, 1982).

Taylor and Orlansky (1987) noted that the degree to which the combat effectiveness of an individual or a unit will be degraded by wearing CW-protective combat clothing is a function of a number of variables including: (1) the ambient conditions of the workplace; (2) the type and extent of CW-protective combat clothing worn; (3) the length of time that the protective clothing is worn; (4) the level of physical activity; (5) the physical conditions of the individuals in the unit; (6) the work/rest cycles; and to a lesser degree (7) the training level of the unit. Taylor and Orlansky (1987) reviewed 12 reports published in the United States between 1974 and 1982; two of these were summary reports. Carr, Corona, Jackson, and Bachovchin (1980) provided a critical review of the literature pertaining

to the effects of wearing CW-protective combat clothing on soldier performance. Carr, Kershner, Corona, and Jackson (1980) reported a critical assessment of troop tests concerned with the effects on soldier performance of CW-protective combat clothing and equipment. Two reports (Carr, 1982; Carr, Corona and Jackson, 1981) were concerned with the effects of chemical warfare decontamination equipment and procedures on soldier performance. Taylor and Orlansky (1987) also reviewed a report by Hanlon, Jones, and Merkey (1982), which was concerned with the effects of MOPP 4 on soldier performance in a tropical environment and reports concerned with the results of a field experiment, Grand Plot III, that tested individual and squad effectiveness in a chemical threat environment (Project Team, 1975; Eifried, 1976).

Carr, Kershner, Corona, and Jackson, (1980) reported the results of a survey of 10 troop tests conducted from 1959 to 1979. The report reviewed the effects of CW-protective combat clothing and equipment on mission effectiveness. The tests included typical infantry tasks at the individual, squad, and staff section level. A mechanized battalion was involved in one test and mechanized rifle companies were involved in two tests. Other combat arms such as armor, artillery, and aviation as well as maintenance activities were involved in a limited number of the tests. Rakaczky (1981) assessed the findings of these tests as follows:

- There was no uniformity in the structure of the tests, the parameters they attempted to measure, or in the manner in which performance was measured. This was attributed to the fact that the tests were performed over a period of 20 years, were conducted by different organizations, and were conducted under different technological and military conditions.
- The greatest amount of data is available for infantry missions and tasks, and cover attack, defense, and retrograde operations for squad, platoon, and company size units. A disadvantage is that most of the data are presented in terms of staytime, the length of time an individual remains in protective gear until he becomes a casualty or until the unit becomes ineffective because of heat stress.
- The duration of most of the tests was too short to be able to assess the effects of rotation of individuals or tasks to maximize unit effectiveness over time.
- There are almost no data for a tank company or battalion.
- Artillery data are limited. There was no live firing, and the scope of tests was limited.

- There was little or no data for any specialized type of combat, such as airborne operations, river crossing operations by engineer units, etc.
- No data were available for cold weather conditions, or for operations over rough terrain or in deserts.
- No extensive testing was done over a variety of MOPP conditions.
- No tests were reported in which females were included.

--Rakaczky, 1981, pp. 13 and 14

The tests indicated that wearing CW-protective combat clothing impaired individual soldier performance. Wearing protective clothing for sustained periods progressively reduced unit effectiveness. Performance degradation increased as the degree of encapsulation increased. One study found that dismounted mobility (foot soldiers) was degraded unacceptably. Another test indicated that amphibious assault was not feasible in the tropics in MOPP 4. Heat stress as measured by staytime, i.e., the time an individual or a unit can stay in MOPP 4, was found to vary with energy expenditure and climatic conditions. A summary of the results of these tests from Carr, Kershner, Corona and Jackson (1980) is reproduced in Appendix A.

A detailed summary of operational degradation while wearing CW-protective combat clothing during large-scale field trials conducted between 1966 and 1968 was provided by Goldman (1981). These trials are significant since performance degradation due to heat stress was eliminated. Mission performance was found to be degraded in four critical combat areas, i.e., firepower, communications, mobility, and support. The results demonstrated that target location and identification, fire accuracy, time to conduct artillery fire orders, road march and assault times, and support functions including ammunition resupply and medical assistance were all significantly degraded by wearing CW-protective combat clothing. The summary by Goldman (1981) is included in Appendix B.

Several recent studies have indicated that psychological stress due to encapsulation and other stress factors can also produce significant performance degradation.

II. METHOD

The following techniques were used to obtain documents for the present review:

- Standard search of the Defense Technical Information Center using key words.
- Search of the Chemical Defense Data Base maintained by the Armstrong Aerospace Medical Research Laboratory (Hala, Chevalier and Unfried, 1986).
- Visit to U.S. Army Research Institute for Environmental Medicine (USARIEM), Natick, Mass.
- Letters of inquiry to laboratories known to be involved in conducting research in the areas of interest.
- Research report bibliographies.

The focus of the present study is a critical review of the human performance and operational performance data contained in the reports obtained. Generally, studies conducted since 1979 were selected.

There is a growing body of literature concerned with the effects that chemical warfare antidotes, i.e., atropine sulfate and 2-PAM chloride, may have on performance decrements. The current paper is not concerned with these reports. An earlier summary was provided by Headley (1982). Reports that are primarily concerned with physiological variables, with the exception of staytime, will also be excluded from this review.

A. STUDY CATEGORIES

Since the early 1980s, the U.S. Department of Defense has sponsored a number of major projects designed to determine performance decrements resulting from wearing CW-protective combat clothing. These efforts fall into three major categories: (1) combined arms exercises; (2) field trials; and (3) laboratory studies. Data for the present report are organized in these categories.

1. Combined Arms Exercises

Combined arms exercises are conducted to provide quantitative information and realistic combat experience for combat, combat support, and combat service support units. They provide data relating to the interactions and interdependences of a number of factors including force structure, doctrine, and materiel for combined arms in a sustained, integrated battlefield situation. These exercises are important in that the data collected are used to validate combat development concepts doctrine, and to determine the effectiveness of and the need for training and materiel development. It is important to conduct combined arms exercises in a nuclear/chemical environment, which simulates an integrated battlefield, in order to determine the effectiveness with which a combined arms force can accomplish its mission under chemical warfare combat conditions.

Combined arms exercises generally use an instrumented battlefield and are conducted over a sustained period of time. The most effective exercises compare a baseline condition with an "exercise" condition which includes one or more parameters. The parameter of interest for the purpose of the present paper is simulated chemical combat threat conditions. These exercises use a trained opposing force, have a defined and previously tested realistic combat scenario, generally provide both objective and subjective data and are supervised by judges and controllers.

Combined arms exercises provide data that can be most readily generalized to a combat situation, but in general are less likely to be as tightly controlled as field trials and substantially less controlled than laboratory studies. Generally, variables used in combined arms exercises have been identified in field and laboratory studies.

2. Field Trials

Field trials are generally more narrowly defined and more tightly controlled than combined arms exercises, but less narrowly defined than laboratory studies. They may include only one combat arm, or a combat support unit. As discussed above, most recent field trials have been conducted for a sustained period, i.e., 24-72 hours to provide data concerning sustained operations in a chemical warfare combat environment.

3. Laboratory Studies

Laboratory studies generally provide the greatest degree of experimental control, investigate more narrowly defined parameters, and are less useful in generalizing to unit performance.

In order to provide a common metric to quantify the performance degradation due to wearing CW-protective combat clothing, we have developed two indices: Percent Time Degradation (D_T) and Percent Accuracy Degradation (D_A). These are defined as follows:

(1) Percent Time Degradation =

$$D_T = \frac{Yct - Yxt}{Yct} \times 100$$

where:

Yct = the time required by a control group wearing combat clothing (but not CW-protective combat clothing) to complete a task

Yxt = the time required by an experimental group wearing CW-protective combat clothing to complete a task.

(2) Percent Accuracy Degradation =

$$D_A = \frac{Yca - Yxa}{Yca} \times 100$$

where:

Yca = the number of hits (normalized per x rounds), errors, etc., by a control group wearing combat clothing (but not CW-protective combat clothing)

Yxa = the number of hits (normalized per x rounds), errors, etc., by an experimental group wearing CW-protective combat clothing.

In some reports that we reviewed, performance degradation was computed using these metrics. In other cases we have calculated the performance degradation indices from available data. For some studies the available data did not permit us to compute performance degradation indices. In another paper, Taylor and Orlansky (1991) have stated that indices for comparing performance decrements across studies are needed. Percent Time Degradation and Percent Accuracy Degradation are two such indices.

Dugway Proving Ground has administered an extensive program known as the Chemical/Biological (CB) Contact Point and Test Program, (Project DO49), to quantify the effects of wearing CW-protective combat clothing on personnel performing military tasks.

According to Wick, Morrissey, and Klopcic (1987) the program consisted of five operational areas:

- Maintenance Operations
- Night Recon Operations
- Missile Operations
- Armor Operations
- Signal Operations.

A number of reports that resulted from these efforts will be a major focus of this review.

In 1984 the U.S. Army Vice Chief of Staff initiated a program to assess the psychological and physiological effects of nuclear, biological, and chemical warfare on extended operations. This program has been called the P^2NBC^2 program, and will also be a major area of concentration.

A number of well-controlled laboratory reports will also be reviewed.

Included in the report are four appendixes which summarize the following aspects of performance degradation:

(1) Appendix A--Mission Degradation Troop Test

(2) Appendix B--Operational Degradation Due to Chemical Protection in Field Trials Without Heat Stress

(3) Appendix C--Empirical Studies of the Effect of CW-Protective Combat Clothing on Performance

(4) Appendix D--Maintenance Tasks.

III. RESULTS

The results are organized in the major study categories: (1) combined arms exercises, (2) field studies, and (3) laboratory studies. The combined arms exercise section will focus on a three-phase report dealing with combined arms in a simulated Nuclear/Chemical Environment (CANE); only the results of CANE Phase I are summarized here.

A. COMBINED ARMS EXERCISE

1. Combined Arms in a Nuclear/Chemical Environment Phase I (CANE)

The CANE Phase I exercise was conducted at the mechanized infantry squad level to determine the effects of simulated nuclear/chemical environment on unit combat operations (Draper and Lombardi, 1986). Eight mechanized infantry platoons conducted two operations of 72 hours each. The first operation, the baseline condition, was conducted under battlefield conditions in which there was no threat of a simulated nuclear or chemical hazard; there was such a threat in the second operation. During the second day of the operation, the platoon was required to operate continuously for 12 hours in MOPP 4 under a nuclear/chemical threat condition.

During each of the 72-hour operations the platoons conducted the following combat maneuvers: seven tactical movements; six preparations for movement; three movements to combat; three hasty attacks; three consolidation/reorganization efforts; and three defenses. The Multiple Integrated Laser Engagement System (MILES) was used to determine hits for direct fires, and indirect fires were simulated by computer software. The exercise units (player platoons) were opposed by a motorized infantry squad when attacking; they were opposed by a platoon when defending.

Assessments of the performance decrements due to the nuclear/chemical threat were conducted for the following categories: (1) close combat, heavy; (2) command and control; (3) communications; (4) fire support; (5) air defense; and (6) conduct support.

a. Close Combat, Heavy

Compared to the baseline situation, the effect of wearing CW-protective combat clothing in the simulated nuclear/chemical threat environment was to significantly decrease the ability to acquire and destroy threat targets. The average number of engagements decreased significantly. The engagement efficiency, defined as the sum of hits and near hits divided by the number of shots fired, also decreased significantly. The average range at which targets were engaged increased significantly. During the simulated nuclear/chemical attacks, the loss-exchange ratio increased significantly to an unacceptable level. For the simulated CW condition, the loss-exchange ratio was above the level that U.S. Army doctrine states as necessary to maintain a successful attack.

Table III-1 summarizes for a number of combat measures the platoon performance for close combat, heavy for the baseline and the simulated nuclear/chemical conditions; it also includes the percentage change in performance measures between the baseline and the simulated nuclear/chemical threat which we calculated from data from Draper and Lombardi (1986). With one exception, targets killed in day defense, all positive and negative values indicate a performance decrement for the simulated nuclear/chemical condition.

b. Command and Control

Compared with baseline, the number of unit commanders assessed as casualties increased significantly during attack conditions for the simulated nuclear/chemical conditions, but the number of commander casualties decreased during defense conditions. More importantly, the time before the next ranking soldier assumed command when the unit leader became a casualty was over 3.4 times as long for the simulated nuclear/chemical condition compared to baseline. For the simulated nuclear/chemical condition, the commanders appeared to be more active, had a higher workload, and appeared to become more fatigued. When wearing MOPP 4, the leaders appeared to be disoriented, and had difficulty regaining orientation even when controllers pointed out prominent terrain features. In the simulated nuclear/chemical condition, there was difficulty in recognizing leaders and squad or platoon members.

One important variable affecting overall platoon performance in the simulated nuclear/chemical condition was the amount of prior nuclear, biological, chemical (NBC) defense training of the leader. This variable was important even when the rest of the soldiers in the platoon had little training. It is interesting to note that none of the leaders reported more than moderate NBC defensive training.

Table III-1. Summary of CANE Platoon Performance for Close Combat, Heavy

Measure of Performance	Baseline	Simulated Nuclear/Chemical	Percent Change
1. Direct Fire Engagements			
All Weapons	--	--	- 52%
M16	--	--	- 54%
2. Engagement Efficiency	83%	67%	- 37%
3. Battle Intensity--Attack shots/min	--	--	- 69%
4. Engagement Range	--	--	+ 52%
5. Engagement of Friendly Forces	4.3%	19.8%	+ 360%
6. Ammunition Expenditures			
Trigger pulls (attack)	--	--	- 43%
Trigger pulls (defense)	--	--	- 22%
7. Targets Engaged			
Attack	72%	54%	- 25%
Defense (day)	64%	61.4%	- 4%
Defense (night)	51%	28.7%	- 44%
8. Targets Killed			
Attack	54%	42%	- 22%
Night defense	28%	21%	- 25%
Day defense	46%	51%	+ 11%[a]
9. Duration of Battle	20.4 min	37.2 min	+ 82%
10. Infantry Attack	23%	53%	+ 32%
11. APC Attack	--	--	+ 130%
12. Loss-Exchange Ratio (Killed attacker/Killed defender)	2.4	3.99	+ 66%

[a] Performance was better under simulated nuclear/chemical condition. All other positive and negative values indicate a performance decrement for the simulated nuclear/chemical condition. (Baseline and simulated nuclear/chemical data from Draper and Lombardi, 1986; percent change calculated.)

There was a significant and important increase in dehydration during the simulated nuclear/chemical condition. At the end of the 72-hour period 83 percent of the soldiers were "well above the value equivalent to 24 hours without fluid intake and 17 percent were clinically dehydrated." (Draper and Lombardi, 1986, p. 2-9)

c. Communications

Compared to the baseline condition the frequency of radio messages increased 47 percent and the duration increased 53 percent during the [illegible] segments for the simulated nuclear/chemical condition.

d. Fire Support

During the simulated nuclear/chemical segment, the frequency of calls for indirect fire support increased by 209 percent during attacks but decreased 11 percent during defense. The duration of calls also increased. The leaders reported that they believed that indirect fire was more lethal than direct fire during the simulated nuclear/chemical condition. The decrease of calls for indirect fire during movement was attributed to the increased workload of leaders and to the difficulty in locating targets.

Table III-2 summarizes the performance during the baseline and simulated nuclear/chemical conditions for command, control, and communications (including calls for indirect fire). It also includes the performance decrement due to the simulated nuclear/chemical threat which we calculated from data from Draper and Lombardi (1986).

e. Air Defense

The time that the mechanized infantry platoon devoted to passive air defense (camouflage) decreased significantly as the simulated nuclear/chemical 72-hour operation progressed and no camouflage activity occurred during the last 26 hours of the operation. In contrast, during the baseline condition, camouflage activity continued throughout the 72-hour period. Compared to baseline, time involved in camouflage decreased by 31 percent and the number of camouflage actions decreased by 39 percent during the simulated nuclear/chemical condition.

f. Combat Support

The average time to conduct a complete personnel, vehicle, and equipment decontamination was 83 minutes. A minimum training period of 2 hours prior to the test provided adequate training. This phase of the exercise was important since it validated the following new decontamination doctrine: (1) vehicle and platoon equipment decontamination was accomplished by a dedicated chemical decon squad with assistance of the combat platoon; (2) personnel and personal equipment decontamination was conducted exclusively by the combat platoon with minimum training (2 hours).

The change in doctrine reduced the workload for chemical decontamination combat support with a resultant force structure reduction. Some soldiers would have received skin contamination during the overgarment exchange which indicates the need for some additional training with agent stimulants.

Table III-2. Summary of CANE I Performance for Command, Control, Communication, and Fire Support

Measure of Performance	Baseline	Simulated Nuclear/Chemical	Percent Decrement
1. Commander Casualties			
Attack	50%	67%	+ 34%
Defense	50%	23%	− 54%[a]
2. Time to Replace Commanders	1.4 min	6.2 min	+ 343%
3. Commander Casualties Replaced			
Attack	58%	23%	− 60%
Defense	33%	33%	0
4. Radio Messages			
a. Battle Segments			
Frequency	..	..	+ 47%
Duration	..	..	+ 53%
b. Movement Segments			
Frequency	..	..	− 8%[a]
Duration	..	..	+ 4%
c. Stationary Segments			
Frequency	..	..	+ 119%
Duration	..	..	− 3%[a]
5. Calls for Indirect Fire			
Attack	..	..	+ 209%
Defense	..	..	− 11%[a]
Duration (less than 10 sec)	71%	50%	+ 30%

[a] Performance advantage for simulated nuclear/chemical condition; all other positive and negative values represent performance decrement for simulated nuclear/chemical condition. (Baseline and simulated nuclear/chemical data from Draper and Lombardi, 1986; percent decrement calculated from their data.)

g. Evaluation of CANE I

Draper and Lombardi (1986) indicated that CANE I had the following deficiencies:

- The majority of the instrumented data for the three platoons was lost.
- The 3-to-1 attacker-to-defender ratio was not maintained for the test platoon. The opposing force platoon was scheduled to attack only one test squad; this did not happen in many defense situations. More importantly, the test report failed to specify the battles during which the 3-to-1 attacker-to-defender ratio was not maintained, therefore nullifying much of the defense data. It should be noted, however, that the report by Draper and Lombardi (1986) used the best available data while accounting for the deficiencies of the test.
- Many of the controllers who provided subjective evaluations of the test were inexperienced, which limited both the amount and quality of the subjective data.

- Planned assessment of simulated chemical casualties was not accomplished.
- The simulations of weapons firing and impact lacked some degree of realism due to safety constraints.

h. Summary of CANE I

In summary, Draper and Lombardi (1986) reported that command and control suffers significantly in the simulated nuclear/chemical environment compared to a non-NBC threat environment. When a platoon leader becomes a casualty, the next senior man assumes command less than 25 percent of the time. They reported that it takes the platoon four times longer to realize the platoon leader is a casualty. It was more difficult to direct fire, maneuver, and maintain accurate platoon orientation. Platoon leaders get lost more easily and find it harder to get reoriented. Platoon leader casualties are twice that of the non-nuclear/chemical environment. Dehydration is a serious problem; 20 percent of the soldiers were seriously dehydrated and were not aware of their dehydrated condition.

Compared to a non-nuclear/chemical environment, Draper and Lombardi (1986) found that communications were degraded by 50 percent; the total time spent on radio traffic increased by a factor of two.

In terms of direct fire, compared to a non-nuclear/chemical environment, Draper and Lombardi reported that it took twice as long to complete an attack. Firing rates are decreased by 20 percent in defense and 40 percent in attack. Almost twice as much manpower is required to complete an attack. The number of casualties per enemy killed increases by 75 percent. There is a 50 percent reduction in the engagement of enemy forces. Four times as many shots are fired at friendly personnel (20 percent compared to 5 percent). Indirect fire is increased by a factor of three over the non-nuclear/chemical environment.

B. FIELD TRIALS

1. Chemical/Biological (CB) Contact Point and Test Program (Project DO49)

a. Degradation of Performance of Maintenance Tasks

Two series of field tests were conducted in 1984 and 1985 to investigate the amount of degradation of various maintenance tasks performed by troops encapsulated in CW-protective combat clothing (MOPP 4), compared with wearing the Battle Dress Uniform

(BDU). The objective of the tests was to determine the effects on representative maintenance operations of wearing CW-protective combat clothing against a chemical attack. The tests were conducted without live fire or the presence of a chemical agent. Wick and Morrissey (1987) reported the results of the 1985 test and Parker, Stearman, and Montgomery (1987) provided a summary report which contained data from these two tests and from other tests. Since the conditions under which the tests were conducted were comparable, the data from the two tests were combined, reanalyzed, and reinterpreted by Montgomery (1987).

In order to determine performance degradation, the time required for troops to accomplish various maintenance tasks when dressed in BDU was compared with the time required when dressed in MOPP 4. The maintenance tasks involved both heavy labor and fine motor skill performance. Each task was performed by 10 teams--5 in 1984 and 5 in 1985. The following maintenance tasks were performed by one to four persons, as indicated:

(1)	Remove and Replace M60A3 Tank Power Pack	four persons
(2)	Remove and Replace M60A3 Tank Transmission	two persons
(3)	Remove and Replace M109 Howitzer BreechBlock	two persons
(4)	Recover M60A3 Tank	four persons
(5)	Repair M60 Machine Gun	one person
(6)	Repair M109 Howitzer Traverse Mechanism	one person
(7)	Repair FADAC Printed Circuit Board	one person

The way in which the field tests were conducted poses significant problems in interpreting the results. The subjects were from the student brigade of the U.S. Army Ordnance Center and School and were trained in the appropriate military operational specialty (MOS), but the team members had no previous experience working together. The tests were repetitive and performance on the tests improved during the testing cycle. If performance on the seven tasks had been stable when wearing the BDU, a straightforward experimental design would compare stable performance in the BDU with performance in MOPP 4. After the decrement was determined for the various tasks, the reduction of the degradation as the result of training to perform the task in MOPP 4 could be determined by giving repeated practice on the tasks in MOPP 4. In the case of the present study, however, baseline performance in the BDU was not established for any of the tasks prior to

testing in MOPP 4. This deficiency in the experimental design of the study has been noted by Wick and Morrissey (1987) and by Montgomery (1987).

For two of the tasks, Remove and Replace M60A3 Power Pack (Task 1) and Remove and Replace M60A3 tank transmission (Task 2), each crew performed the task twice--once in BDU and once in MOPP 4. For these tasks, approximately half of the crews performed the tasks first in BDU and the other half first in MOPP 4. For the remainder of the tasks, multiple trials were conducted, but no attempt was made to counterbalance the order of trial presentation. Since the data on all tasks indicated an improvement in performance over trials, the analysis and interpretation of degradation due to MOPP 4 was confounded by improvement on the tasks during the study.

Regression analysis was used to analyze the data (Wick and Morrissey, 1987). The following general regression expression was used to estimate the dependent variable, i.e., the time to complete the task, by quantifying the relationship of several independent variables:

$$T = T_0 + a(x) + b(y) + e$$

where:

$T =$ the time in minutes to complete the task

$T_0 =$ the practiced, unencumbered time

$x =$ clothing type

$y =$ order in which an event was started

$e =$ the error term.

Wick and Morrissey (1987) assumed that x would be zero when BDUs were worn, and one for MOPP 4, and y was assigned a one if the event was being completed for the first time, and zero if the event had been completed more than one time. Thus, the expression without the error term is:

$$T = To + a + b$$

where

$a =$ the correction in minutes for MOPP 4

$b =$ first trial practice effect.

The MOPP 4 degradation factor for any task is $\frac{T_o}{T_o+a}$ and the correction factor is $\frac{T_o+a}{T_o}$ (Wick, Morrissey, and Klopcic, 1987; Wick and Morrissey, 1989; Wick and Morrissey, 1987; Wick, 1988). The correction factor when multiplied by T_O gives the expected time to complete a task in MOPP 4 (Wick, 1988). Davis et al. (1990) later called the correction factor a Performance Decrement Factor.

Consequently the regression analysis was used to predict and account for the effects of learning by separating the effects of the first trial from later trials on each task (Wick and Morrissey, 1987; Parker et al., 1987). The regression analysis assumed that learning occurred only on the first trial. For one of the tasks, Recover M60A3 Tank, the regression analysis indicated a 90 percent performance degradation as a result of MOPP 4 for the 1984 tests but a 10 percent degradation for the 1985 tests (Montgomery, 1987). Consequently, Montgomery questioned the assumption that learning was important only for the first trial. He concluded that the "regionalized statistical approach," which accounts for a continual learning process, was appropriate to determine degradation effects of MOPP 4. According to Montgomery the regionalized statistical approach not only uses the magnitude of a measurement but also considers its location in time and space (Montgomery, 1987).

For each trial he reorganized the data according to the order that BDU or MOPP 4 dress was used. Several of the Montgomery data tables are presented in Appendix D to illustrate problems with the experimental design and to provide additional analyses.

Montgomery (1987) graphically presented the order data (time by trial) and concluded that the "learning curves are so strong they tend to bury all other effects in the data" (Montgomery, 1987, p. 17). Montgomery correctly pointed out that performance improvement is a result of two factors--learning to perform the task and adaptation to MOPP 4, but the small number of subjects for each trial and an inadequate experimental design made it difficult to separate the two effects.

Montgomery (1987) reported that, when the regionalized statistical analysis approach was used, performance on tasks using gross motor skills was degraded about 30 percent due to MOPP 4. He estimated that the degradation could be reduced to about 20 percent through regularly scheduled training in MOPP 4. He also noted that his analysis indicated performance in BDU can be increased between 100 and 200 percent through repeated practice of the tasks. He found that fine motor skills were degraded an average of

60 percent by MOPP 4. He estimated that the degradation could be reduced to 50 percent or less through training in MOPP 4. Indeed the importance of training is underscored by the fact that "adaptation to and functioning in MOPP improved with each additional try" (Montgomery, 1987).

Table III-3 was constructed by the current authors to summarize Montgomery's regionalized statistical analysis approach and an analysis based on Percent Time Degradation (D_T) using the data presented by Montgomery (1987).

Table III-3. Summary of Percent Time Degradation of Maintenance Task Due to MOPP 4

Task Number	Title	Montgomery (1987)	Taylor & Orlansky (D_T)
1	R&R M60A3 Tank Power Pack	35% ± 20%	25.4%
2	R&R M60A3 Tank Transmission	50%	38.8%
3	R&R M109 Howitzer Breech Block	25% ± 25%	26%
4	Recovery of M60A3 Tank	--[a]	--[a]
5	Repair of M60 Machine Gun		0[b]
6	Repair of M109 Howitzer Traverse Mechanism	50% ± 30%	31-37%
7	Repair of FADAC Circuit	--[a]	--[a]

[a] Lack of data for BDU prevents calculation of degradation.

[b] Weighted mean for first three trials (BDU $\overline{X} = 10.7$, $N = 16$; MOPP 4 $\overline{X} = 10.6$, $N = 17$).

It is important to discuss several lessons learned from the above analysis of the tests. Since it is expensive to conduct field tests such as these, proper attention should be given to the experimental design of the test in order that the results can be interpreted. These field tests had several deficiencies. First, the teams and/or individuals were not well trained in the tasks to be performed. It is important to use subjects that are well trained in performing the tasks. Second, a stable performance baseline in BDU was not established prior to the introduction of the experimental condition--MOPP 4. If possible, a performance baseline should be established prior to the introduction of MOPP 4. If this is not possible, a counter-balanced design should be used in an attempt to balance practice and learning effects. Third, in a number of cases, no meaningful comparisons could be made between BDU and MOPP 4 due to lack of data. Enough subjects or trials should be conducted to permit comparisons between the baseline and experimental conditions and to permit inferential statistics with enough "power" to enable the results to be used with confidence. Fourth, for none of the tests were enough trials conducted after the

introduction of MOPP 4 to determine the effect of training in MOPP 4 although this was stated as an objective of the tests. After introducing the experimental condition, it is important to conduct enough trials in MOPP 4 to demonstrate the effect of training in MOPP 4.

In the present case, an extensive field experiment was conducted without an appropriate experimental design. The lack of attention to experimental design and statistical procedures has resulted in results that are difficult to interpret.

b. Performance Degradation of Night Reconnaissance Mission

Ramachandran and Montgomery (1987) reported a field test conducted at Camp Pendleton in August 1985, which compared the effectiveness of marines performing a simulated night reconnaissance mission under BDU and MOPP 4 conditions. The study was also designed to determine if training would reduce performance degradation. The tasks for the mission were:

(1) Route reconnaissance
(2) Photographing a target
(3) Emplacement of a claymore mine
(4) Air and water sampling for contamination
(5) Hasty sketching of a dam
(6) Moving between different objectives.

Three four-person teams performed each task once in BDU and twice in MOPP 4. The dependent measure was time to perform the task. Table III-4 indicates the order in which each team performed the trial.

Table III-4. Trial Order

Team	1st	2nd	3rd
1	MOPP 4	BDU	MOPP 4
2	MOPP 4	MOPP 4	BDU
3	BDU	MOPP 4	MOPP 4

The authors reported that the data were not sufficient to permit statistical evaluation. They found that "Since learning and adaption occurred each time a team performed a task, it was impossible to identify statistically the specific performance degradation due to

MOPP 4." They reported that "... such an analysis could have been possible if the trials had been repeated with more soldiers who were familiar with the performed tasks" (Ramachandran and Montgomery, 1987, p. 5).

The authors averaged, for two teams, the performance times for each task performed under the MOPP 4 condition for each trial order, i.e., each data point consisted of the average of two teams for each ordered trial (1st, 2nd, 3rd). For example, for the Route Recon task Teams 1 and 2 performed the task for the first trial in MOPP 4, Teams 2 and 3 performed the task for the second trial in MOPP 4, and Teams 1 and 3 performed the task for the third trial in MOPP 4. When the data are examined in this manner, there is an improvement over trials for most tasks, but the effects of learning the task and adapting to MOPP 4 are confounded.

The data for the BDU condition were also displayed by the order in which the task was performed. These data consisted of a single datum per trial since the BDU condition was performed only once by each team. Based on data from the three ordered trials, Ramachandran and Montgomery (1987) concluded that: (1) a comparison of movement times between trials in BDU and MOPP 4 resulted in a time increase of 150 to 200 percent for MOPP 4; (2) practice improved performance by 66 percent for BDU and by 5 to 10 percent for MOPP 4.

Table III-5 compares the means of these ordered data from Ramachandran and Montgomery (1987) for the three teams averaged across five tasks, i.e., route recon, move #1, move #2, water sample #2, and extraction move for the BDU and MOPP 4 conditions. The data from Ramachandran and Montgomery (1987) were used to calculate the percent improvement based on a comparison of the difference between trials 1 and 3 divided by trial 1; these results are also contained in Table III-5. The results indicate an improvement of 66 percent for the BDU condition and 17 percent for the MOPP 4 condition.

We also calculated percent time decrement (D_T) for MOPP 4 compared to BDU for the three ordered trials using the data in Table III-5. For ordered trial 1, $D_T = -6\%$; for ordered trial 2, $D_T = -30\%$; and for ordered trial 3, $D_T = -163\%$. Thus while improvement was found with practice for both BDU and MOPP 4, the performance decrement resulting from wearing MOPP 4 compared to BDU increased as performance in BDU approached asymptote.

Increased heat storage as a result of the MOPP 4 configuration was the primary problem during the trials. Perspiration resulted in loss of mask integrity and caused breathing problems. Boots slipped, snagged on vegetation, and provided unnatural feedback of the ground; voice communication was poor. "Stealth was totally lacking . . . because of high noise levels, slow movement, tripping and snagging, bunching, and poor use of protective cover" (Ramachandran and Montgomery, 1987, p. 15). The data also indicate the significant time penalty due to wearing MOPP 4. Further, the data indicate that performance in MOPP 4 can be improved with practice. The experimental design results in a confounding of the improvement due to learning to do the tasks better and learning to perform the tasks in MOPP 4.

Table III-5. Mean Time for 3 Teams Performing Five Tasks by Trial Order for BDU and MOPP 4 (N = 5) (Data from Ramachandran and Montgomery, 1987, percent improvement calculated)

BDU					MOPP 4				
Trial (Mean Time in min)				Improvement	Trial (Mean Time in min)				Improvement
1	2	3	$\bar{X}$	$\frac{T1 - T3}{T1}$	1	2	3	$\bar{X}$	$\frac{T1 - T3}{T1}$
89	63	30	60.7	66%	95	82	79	85.3	17%

Wick, Morrissey, and Klopcic (1987) reported the results of night reconnaissance operations similar to those reported by Ramachandran and Montgomery (1987) but conducted at Camp Pendleton in September 1985. The program was designed to evaluate the operational capabilities and to quantify the degradation of performance which results from wearing MOPP 4. The measure of degradation was the time difference between task performance with BDU and MOPP 4. The subjects were three teams of four members each. None of the teams practiced the exercise or received special instruction in wearing or completing the tasks in MOPP 4. The tests were repetitive and the subjects gained experience during the course of the field trial.

The tasks were performed in the following order:

(1) Route reconnaissance

(2) Photograph a target

(3) Move to first objective

(4) Emplace a claymore mine

(5) Take an air sample

(6) Move to second objective

(7) Take first water sample

(8) Make hasty sketch of dam

(9) Take second water sample

(10) Move to extraction point.

Each of the three teams completed the above tasks three times over a period of 8 days. The clothing conditions are shown in Table III-6:

Table III-6. Trial Order by Team

Team	1st	2nd	3rd
1	BDU	MOPP 4	MOPP 4
2	MOPP 4	BDU	MOPP 4
3	MOPP 4	MOPP 4	BDU

The field data collected was the time in minutes for each team to complete a task. Regression analysis was used to analyze the data. The regression equation $T = T_0 + a + b$ previously discussed was used to account for time to complete the task.

In an attempt to account for the fact that no performance baseline was established prior to conducting the test, the authors account for the effect of practice by including in the regression analysis an experimentally determined linear correction term for first trials. This assumes that the effect of practice occurs only on the first trial. In other studies Montgomery (1987) has noted that this assumption was not warranted, but there was no independent way to test the assumption for this study.

Using the regression analysis approach, degradation factors were computed for each night reconnaissance task. The inverse of the degradation factors, the MOPP correction factors, and the probable range are presented in Table III-7.

Using the regression analysis approach, the greatest effect of MOPP 4 was found for the movement tasks. The authors also reported that stealth was generally lost during night movement while wearing MOPP 4.

Table III-7. Night Reconnaissance MOPP 4 Correction Factors and Probable Range

Task	MOPP 4 Correction Factors	Probable Range
Route Recon.	1.2	0.9-1.5
Move to 1st Objective	1.4	1.2-1.7
Take Air Sample	1.0	0.6-1.2
Move to 2nd Objective	1.5	1.3-1.8
Take 1st Water Sample	1.1	0.3-1.8
Hasty Sketch of Dam	1.1	0.8-1.3
Take 2nd Water Sample	1.3	1.0-1.7
Move to Extraction Point	1.4	1.0-1.9

c. Performance Degradation of HAWK Missile Operations

Parker and Stearman (1987) reported the performance degradation of HAWK missile operations as a result of wearing MOPP 4. Six marine assault fire units, three from Yuma, Ariz., and three from Cherry Point, N.C., conducted HAWK missile launch operations, which were repeated 3 to 6 times on 3 consecutive days. During 1 day the marines were dressed in BDU and for 2 days they were dressed in MOPP 4. The time to set up the equipment for a launch of the HAWK missile, the time to disassemble and prepare for movement, as well as the total time of the operation were recorded. Times were recorded for 42 tasks.

The order of performing the operation for the three units at each site is shown in Table III-8:

Table III-8. Order of Conditions

Unit	1st Day	2nd Day	3rd Day
1	BDU	MOPP 4	MOPP 4
2	MOPP 4	BDU	MOPP 4
3	MOPP 4	MOPP 4	BDU

Separate statistical analyses were performed on task data collected at the two test sites. Kruskal-Wallis Tests were used to test for differences among the nine cells for each of the 42 tasks. Two-way analyses of variance (condition by unit) with unequal numbers

of observations were performed. When significant differences were observed, Mann-Whitney U tests were used to compare the means two at a time.

The Kruskal-Wallis Test indicated a significant difference in performance times for 34 of 42 tasks at Cherry Point and for 39 of 42 tasks at Yuma. The ANOVAs indicated a significant difference for: (1) Conditions, for 5 tasks at Cherry Point and for 9 tasks at Yuma; (2) Units, for 10 tasks at Cherry Point and 13 tasks at Yuma; (3) Interaction, (Conditions by Units) for 22 tasks at both Cherry Point and at Yuma. An analysis of the interaction indicated that the time to perform a task was longest for the first performance regardless of the condition.

Again, the lack of prior training on the tasks limits the interpretation of the data. It is clear there is a confounding of learning to perform the task and adapting to wearing MOPP 4.

Morrissey and Wick (1989b; 1989c) analyzed the same data of the field studies conducted at Cherry Point and Yuma, respectively. The Cherry Point field test was conducted in a warm environment (temperatures 80° to 95°F) with high humidity. The Yuma field study was conducted in a moderate environment (temperature 60° to 85°F) with low humidity. As in the Parker and Stearman (1987) study, the measure of degradation was the time to perform the various tasks in BDU and MOPP 4. The performance degradation of the three HAWK Assault Fire Units at both Cherry Point and Yuma were analyzed by Morrissey and Wick (1989a; 1989b) in terms of five end items. Table III-9 shows the conditions and the source of correction factors for Cherry Point and Yuma.

Table III-9. Range of Correction Factors for Tasks for Five Items of HAWK Missile Assault Fire Unit Equipment (From Morrissey and Wick, 1989b and c)

Equipment	Range of Correction Factors for Tasks	
	Cherry Point	Yuma
Platoon Command	1.1-2.3	0.7-1.4
Continuous Wave Acquisition Radar	1.4-2.0	1.0-1.4
High Power Illumination Radar	1.3-2.8	1.1-1.6
Launcher	1.0-2.8	0.7-1.6
Pulse Acquisition Radar	1.0-2.2	0.7-1.6

The range of correction factors on the individual items of equipment were higher for the Cherry Point operation as compared to Yuma. Morrissey and Wick (1989a) reported that the correction factor to set up and prepare to fire a missile, a measure of the efficiency of the assault fire unit, was 1.4 for Cherry Point "which is approximately the same as that obtained during the Yuma trials."

d. Armor Operations I

The Armor Operations I investigated the ability of tank crewmen to perform their tasks while in MOPP 4 (Barry, Stack, Henry, Enright, and Welch, 1987). This study included acquiring and engaging targets and mission degradation of tank platoons due to wearing MOPP 4 during a defensive operation. The field trial evaluated mission performance during a scheduled training exercise; the availability of personnel was limited. The performance of personnel in the BDU was used as a baseline for comparing degradation. The field trial consisted of the following four phases: (1) planning and preparation for defense; (2) movement from assembly area to battle positions; (3) enemy engagement; and (4) consolidation. Time to perform the various tasks during the four phases of the operation was the primary performance measure but, the number of rounds fired and the number of target hits were recorded during the enemy engagement phase. A degradation factor was calculated by dividing the time to conduct the operations in MOPP 4 by BDU time for the respective operation.

Three tank platoons conducted nine armor operational trials; three trials were conducted in BDU and six trials were conducted in MOPP 4. Each platoon consisted of four tanks. Each trial consisted of one or two repetitions of armor operations. Each platoon conducted one trial in BDU and two in MOPP 4. Platoon A and C conducted the first trial in BDU and platoon B conducted the third trial in BDU. The field trial was conducted under a wide range of temperature conditions, i.e., 7.6°C to 28.2°C (45.7°F to 82.8°F).

The Mann-Whitney U Test was used to analyze the data due to small, uneven, and non-normally distributed samples.

All phases of operations were successfully completed in MOPP 4 but the following two were performed significantly more slowly in MOPP 4 than in BDU: (1) Phase: Planning and Preparation for Defense; Task: boresight M85 .50 caliber machine gun (degradation factor 1.2); (2) Phase: Movement from Assembly Area to Battle Position; Task: Conduct bounded overwatch (degradation factor 1.5).

The exercise was conducted for 2 consecutive days for about 6 hours per day. There was a time decrement for the above two tasks on the second day, but there was an improvement in the time to perform the bounded overwatch task (1.2 vs 1.5). The boresight of the machine gun task showed more degradation on the second day (1.6 vs 1.2). The bounded overwatch maneuver is used when contact with a hostile force is expected. The two sections move by "bounds" during which one section is positioned to "overwatch" and provide supporting fire as the other section moves.

The authors recommended that armor units emphasize training under CW-conditions to ensure competent individual and unit performance.

Poor visual perception and lack of finger dexterity were viewed as the primary cause of the boresighting performance degradation. Evaluator comments included: "impossible to boresight .50 caliber with gas mask and rubber gloves"; "can't get [a] good lay on target, let alone use binoculars"; "rubber gloves cumbersome in handling allen wrench for boresighting .50 caliber, mask limits actual accuracy of . . . boresighting on target," Barry et al. (1987, p. 22).

The mean performance times were 11.5 min in BDU and 16 min in MOPP 4 a D_T (time decrement calculated from Barry et al. data) of −39 percent.

Morrissey and Wick (1989a) used regression analysis on the same data to compute correction factors and probability range for six tasks. The results of this analysis are shown in Table III-10.

Table III-10. Correction Factors and Probability Range for Armor Tasks (From Morrissey and Wicks, 1989a)

Task	Correction Factor	Probability Range
Prepare Driver Station	1.1	0.8-1.4
Check Engine and Transmission In Fluid Levels	1.2	0.9-1.5
Perform Preventative Maintenance and After Operations Checks and Service	1.2	0.9-1.4
Platoon Movements	1.6	1.4-1.8
Target Acquisition	1.0	1.0
Firing Accuracy	1.0	0.9-1.0

e. Performance Degradation of Communications

Stack and Sager (1988) investigated the effect of wearing MOPP 4 on radio teletypewriter operation in a simulated tactical environment. The operational scenario consisted in setting up and breaking down the communication equipment and typing word lists (simulation of message traffic). Two factors were investigated: (1) MOPP 4 versus BDU; and (2) level of experience. The test was conducted during a scheduled field training exercise and the performance measures used were time and accuracy. Eight teams of five members each were used as subjects. A total of 76 trials were conducted; 24 trials were conducted in BDU and 52 trials were conducted in MOPP 4 over two days. The results indicated that the teams were able to successfully conduct the communications operations while wearing MOPP 4 but the times to accomplish the following four tasks were significantly longer than the task times for BDU: (1) installation and camouflage of equipment, correction factor of 1.6; (2) communication (type word lists), correction factor of 1.3; (3) disassemble equipment, correction factor of 1.4; (4) disassemble camouflage, correction factor of 1.3. Performance improved on the degraded tasks for the second day.

The Mann-Whitney U Test was used to test for significant differences for 11 tasks concerned with installation and camouflage of radio teletypewriter. Seven of the 11 tasks had significantly better performance when performed during the second MOPP 4 day than during the first. For three of the tasks the performance of the second MOPP 4 day was better than the performance in BDU. It is clear that a stable baseline was not established for performance in BDU. Consequently, the effects of learning to perform the task are confounded with the effects of training in MOPP 4.

Wick and Morrissey (1989) analyzed the data for selected Radio Teletypewriter operations; Table III-11 lists the correction factors and their probability range.

Table III-11. Correction Factors and Probability Range for Radio Teletypewriter Tasks (From Wicks and Morrissey, 1989)

Radio Teletypewriter Tasks	Correction Factor	Probability Range
Install Generator	1.4	0.9-1.8
Camouflage Trailer	1.3	1.2-1.5
Camouflage Truck	1.0	1.0-1.2
Install Antenna	0.9[a]	0.8-1.0
Install AN/GRC 106	0.8[a]	0.6-1.1
Install AN/MRC 138	0.7[a]	0.3-1.1
Remove RATT	1.2	1.0-1.3
Remove Antenna	1.3	1.1-1.5
Remove Trailer	1.2	1.0-1.3

[a] Probably not degraded.

The results indicated that several tasks were not degraded by wearing MOPP 4 and all tasks were completed.

2. Psychological and Physiological Effects of NBC and Extended Operations (P^2NBC^2)

The Airland Battle doctrine requires extended operations under integrated battlefield conditions where NBC agents are employed. To determine the ability of combined arms forces to operate under NBC conditions, the Vice Chief of Staff of the Army, on May 1984, initiated a program to assess the psychological and physiological effects of NBC and extended operations on combat vehicle crew performance (P^2NBC^2). The objectives of the program were to: (1) measure the physiological and psychological effects of the NBC environment and of sustained operations on systems in combat; (2) provide data for operational risk factors analysis for field commanders; (3) determine the effect of training, doctrine, and equipment on crew performance and endurance; and (4) support the development of training, doctrine, organization, and materiel. Blewett (1991) describes three studies conducted under the P^2NBC^2 program to demonstrate that the program focus is on the NBC operation as a complete system which consists of the soldier, equipment, doctrine, training, and organization all tested in a realistic field environment.

a. Armor Operations

Ellis, Elliott, Johnson, Pimental, Rauch, and Smith (1986) reported the results of a field test which was conducted to determine the decrement in performance of armor crews dressed in MOPP 4.

In order to reach the test objectives and test safety factors and test instrumentation, the following three-phased approach was used:

Phase IA	Baseline Testing-Work-Rest cycle in M60A3 Turret Training (24 hours)
Phase IB	Baseline Testing-Exhaustion in M60A3 Turret Trainer (24 hours)
Phase II	Baseline Testing-Stationary Tank (24 hours)
Phase III	Composite Platoon with Tactical Scenario (72 hours).

Phase IA. The purpose of Phase IA was to determine if crew members could perform assigned duties for a 24-hour period in a moderate thermal environment using the M60 Turret Trainer and performing under the following two CW-protective combat clothing conditions:

- BDU with NBC mask and combat vehicle crewman (CVC) helmet
- MOPP 4 and CVC helmet.

Due to a limited number of volunteers only condition two (MOPP 4 and helmet) was tested. A work-rest cycle of 2 hours of intensive mental and physical activity in MOPP 4 and 1 hour in a cool environment without MOPP 4 was used. The work task simulated the procedures used for engagement of multiple targets (58 targets during 2-hour period). In addition, the work cycle included the following: encode or decode a message, identify 10 vehicles and perform the following psychological tests: Logical-Reasoning, Encode-Decode, and Trails Sequential Spatial Test and the Walter Reed Performance Assessment Battery (PAB).

Two three-man tank crews participated in the Phase IA test. The subjects, without penalty or coercion, could terminate the test at any time. The primary performance data collected related to the gunnery tasks required for each engagement. Accuracy data was recorded via two video cameras. One of the two crews completed the 24-hour test. The individual endurance times ranged from 13.88 hours to 24.00 hours with an average of 19.92 total hours. Target engagement times increased throughout the test (linear function). The crews maintained the ability to accurately process information but lost speed over the test; a significant decrement was found after 7 hours.

Phase IB. During this phase, the rest period was eliminated and an ammunition loading exercise, which consisted of loading 63 rounds, was included. The CW-protective combat clothing conditions and number of subjects used in Phase IA were used in this phase.

As in Phase IA, target engagement times increased throughout the test; the engagement time trend was determined to be a linear function. Neither crew lasted longer than about 9 hours. For one crew the loader passed out after 9 hours; for the second crew the loader had to be carried out after about 7 hours. Observations indicated that the loaders' performance on basic tasks degraded after only 3 hours. Accuracy on the psychological tests was maintained but speed decreased as the tests progressed; a significant decrement was found after only 2 hours.

Phase II. The purpose of this phase was to compare the ability of crews to perform assigned duties in a stationary M60A3 or M1 tank with hatches closed while wearing MOPP 4 or mask only. The engagement task was similar to the previous phases but the ammunition loading task consisted of loading 63 main gun rounds for the M60A3 and 55 for the M1. Full crews (tank commander, gunner, loader, and driver) were used. Data collection was similar to Phase IB. Target engagement times were plotted as in previous phases. Engagement time increased throughout the test; the time trend was determined to be a linear function.

The average individual crew member endurance times were 8.73 hours for the M60A3 and 5.25 for the M1. No crew in either MOPP 4 or mask only was able to complete more than 11 hours. The average crew lasted for 10.09 hours in the M60A3 and for 6.41 hours in the M1.

Phase III. The differences in performance under simulated NBC conditions between M1E1 (later type classified as M1A1) tanks equipped with microclimate cooling and overpressure, and M60A3 and M1 tanks without microclimate cooling and overpressure were investigated. The test consisted of a platoon composed of one M1E1, one M1 and two M60A3 tanks. The platoon conducted, under simulated NBC conditions, continuous tactical operations for 72 hours against an opposing force.

The tactical scenario was made as realistic as possible. The test was designed to observe the effects of the contaminated environment on the platoon's, the crew's and the individual's ability to perform tasks required during a simulated combat mission. The

tactical scenario consisted of the following components: movement to contact, hasty attack, defense, offense, and defense against aircraft.

> The test was designed to address the following issues:
>
> - Are the M1E1 and related NBC equipment reliable for extended operations?
> - What degradation in crew performance results from employing a fully combat loaded M1E1 during extended operations in a contaminated environment?
> - How long can each volunteer crew member remain in an M60A3 tank with hatches closed wearing either (1) an NBC protective mask or (2) full MOPP 4 gear before reaching his confinement or performance limits, where he becomes incapable of completing his assigned duties?
> - How long can each volunteer crew member remain in a M1E1 tank with its hatches closed and overpressure on, wearing underwear, NOMEX, microclimate cooling gear/Kevlor vest and either battle dress overgarment (BDO) or chemical protective overgarment (CPO), before reaching his confinement or performance limits, where he becomes incapable of completing his assigned duties?
> - Is the proposed load plan for the M1E1 adequate?.
>
> --Ellis et al., 1986, pp. 2-89, 2-90

The MILES was used to enhance reality and provide crew members immediate feedback on kills and misses during the gunnery portion of the scenario. When a weapon is fired the MILES interprets the effect on the target based on the weapon characteristics, accuracy of the engagement, and a predetermined hit probability, and triggers an audio and visual effect on the target vehicle. If the engagement results in a "kill" the target vehicle's weapon systems are disabled.

The opposing force was a platoon equipped with five M551 tanks which were modified to represent Soviet T-62s and BMPs. The opposing forces were trained in Soviet tactics.

As in the earlier phases, video cameras were used to collect performance data for gunnery tasks. Each crew member was monitored for physical appearance, heart rate, and rectal temperature. Psychological data were collected as in the earlier phases.

The average crew member endurance times for the M60A3 was 7.25 hours; for the M1, 6.95 hours; and for the M1E1, 16.78 hours. The average M1E1 endurance time was significantly different (at the 99 percent level of confidence from both the M60A3 and the

M1 endurance times). There was no significant difference between M60A3 and M1 endurance times. When two of the four crew members in a tank withdrew, the tank was considered operationally ineffective and was withdrawn from the test. The average crew operational loss time for the M60A3 was 7.83 hours; the range for the six crews was 4.65 hours to 12.65 hours. The average crew operational loss time for the 3 crews in the M1 was 7.81; the range was 3.83 to 12.65 hours. The average crew operational loss time for the three crews in the M1E1 was 16.94 hours; the range was 13.32 to 23.17 hours.

Although none of the tanks completed the 72-hour mission scenario, the endurance times for the crews in M1E1 were 2-3 times longer than the M1 or the M60A3. There was no difference in the endurance times for the M60A3 and the M1 crews. In no case was the crew member removed due to exceeding the rectal temperature. The symptoms reported by crew members terminating included severe headache, nausea, dizziness, fatigue, cramps in legs, blurred vision, poor hearing, and inability to concentrate.

The results of the MILES engagement indicated that all vehicles hit during the test had crews dressed in MOPP 4 or tanks with overpressure. The kill ratios for vehicles with crews dressed in MOPP 4 that continued after 6 hours degraded rapidly; the M1E1 kill ratio remained relatively constant throughout the test. The MILES average kill ratio for the M1E1 in a night defense scenario was four times better than tanks in MOPP 4 and two times better during daylight defense.

The results of the evaluation of a total of 88 combat mission tasks indicated that for 18 tasks the criterion was not met (20.45 percent); for 44 tasks the criterion was partially met (50 percent) and for 26 tasks the completion criterion was fully met (29.54). All of the 18 tasks that were not met were directly related to the CW-protective combat clothing. For instance, the crews could not properly establish communications, and the platoon was extremely vulnerable to air attack. No aircraft sortie during the test was detected or engaged by any of the 12 tanks. The platoons could not effectively reorganize after confrontation with the opposing force. The platoons had "extreme difficulty moving cross-country, particularly at night and during periods of reduced visibility. They also had extreme difficulty in detecting targets while over watching the movement of their own vehicles" (Ellis et al., 1986, p. 2-107). The platoons were very limited in preparing and occupying battle positions. The platoons were also unable to provide adequate local security and were extremely vulnerable to dismounted attacks particularly at night.

In addition to tactical operations, the following tests were conducted: (1) gunnery subtest, (2) boresight subtest, (3) entry/exit procedures subtest, and (4) hammock and Preventive Maintenance Checks and Services (PMCS) subtest.

The gunnery subtest was designed to measure the degradation in gunnery performance when an M1E1 crew engages targets in a chemically contaminated environment; no useful gunnery data were collected during the scheduled test.

The boresight subtest was designed to assess the effects of contaminated chemical conditions on the basic gunnery task of boresighting the 120-mm cannon. Three subjects were trained in the boresighting procedure and three baseline trials were conducted in BDU. The test was performed in MOPP 4 and simulated overpressure in an M1 (the M1E1 was not available; the M1 has a 105-mm cannon). The average time (min:sec) to boresight in BDU was 7:15 for the primary method (range was 6:55-7:40) and 7:40 for the alternative method (range was 7:20-8:10). The average time in MOPP 4 with overpressure was 72:47 for the primary method (range was 70:19-74:43) and 80:23 for the alternative method (range was 79:08-81:10).

The boresight accuracy was verified for the primary and alternative methods for all three trials performed in BDU and for all three trials for the primary method in MOPP 4 with overpressure. The boresight was not verified for any of the three trials using the alternative method in MOPP 4 with overpressure. The loader had trouble focusing through the Pye-Watson Device with the protective mask using the primary method, and was unable to complete the task using the alternative method since the threads on the end of the gun tube could not be seen clearly enough to complete the boresight properly.

The task of boresighting an M1E1 tank wearing CW-protective combat clothing is feasible but takes 10 times as long as in BDU.

The objective of the entry/exit procedures subtest was to evaluate the comprehensive means of the draft entry and exit procedures for the M1E1 tank. The basic issue was to determine if the crew can reestablish an uncontaminated environment after reentry into the tar' The average time to complete the entry/exit procedures for one crewman was 101 minutes and 38 seconds. Ellis et al. (1986) indicated that going from MOPP 2 (inside M1E1) to MOPP 4 outside the tank and disconnecting from the micro-cooling system can be devastating for the crew member exiting the vehicle.

The objective of the hammock and PMCS subtest was to evaluate an M1E1 crew's performance of critical preventive maintenance checks and services and to use a hammock

for resting during extended operations under CW conditions. The subtest was to determine if a hammock can be mounted safely inside the M1E1 tank without moving equipment and if crews can sleep in the hammock. The results indicated that a hammock could be strung if the main gun was fully raised to provide clearance for a crew member unit to sleep in the hammock. Safety was compromised, in part, since the person was suspended over the main gun. Since turret power was on, engagement of the gunner's or the tank commander's control handles could result in injury to the sleeping crew members. Consequently, the turret gun drive would have to be immobilized to assure safety. The loader was able to accomplish all preventive maintenance checks and services. These consisted primarily of checking the air intake grill for blockage, checking the suspension systems, and clearing all vision blocks and optics. The entry and exit procedure took more time than the PMCS. Sleeping in the hammock was judged to be more restful than sitting in the gunner's seat.

Phase IV. Glumm (1988) reported a field trial, IRONMAN, designed to observe operations of the M1 tank under simulated NBC conditions for 72 continuous hours and to observe the effects of modifications in equipment and procedures on crew performance and endurance. This study is Phase IV of the previous study reported by Ellis et al. (1986). Twelve armor crews (48 crewmen) participated in the study which involved two M1 test vehicles enclosed in the moving target simulator. The performance and endurance of 12 crews were measured during a simulated tactical scenario under one of the following five test conditions: Baseline (two iterations), Training/Doctrine, Hardware, Combined, and a Modified Combined condition. Two crews participated in each of the iterations. During the Baseline conditions, crews received clothing, equipment, and M1 hardware currently in the inventory and the crews conducted operations based on current training and doctrine. In the Training/Doctrine condition crews used modified procedures. In the Hardware condition, crews wore a different protective mask and used newly developed equipment. The Combined condition combined the Hardware and Training/Doctrine conditions. The Modified Combined Condition was the same as the Combined except the XM42 protective mask was worn instead of the XM43 and the crew had music, a commercial beverage and crew rotation was used. Each test iteration was 1 week long. The tests were conducted under temperate climatic conditions (temperature range 21.7-24.6°C or 71.1-76.3°F).

Based on core temperature data, heat stress was not a factor but no crew member completed the 72-hour field trial. When 2 members of each four-member crew withdrew, the crew's participation in the trial was terminated. The staytime for individual crew

members ranged between 3 and 32 hours and the mean time of withdrawal was 14.5 hours. Sixty-three percent of the crewmen who withdrew, did so between 8 and 13 hours. The four baseline crews averaged 22.4 hours; the range was from 16.5 to 32.3 hours. The endurance of the other crews for the other four experimental conditions ranged from 9.8 to 23.5 hours. The mean crew endurance time for the four experimental conditions was 13.6 hours. The most common symptoms included heat discomfort and sweating, nausea, breathing difficulties, and headaches. None of the crewmen was withdrawn due to having reached the physiological limits (defined by core temperature or heart rate). Performance measures were recorded for target engagement, target tracking, message encoding and decoding, and driver skill. Other tasks performed during the "resupply" period (every 6 hours) were ammunition resupply, refueling, weapon assembly and disassembly, and vehicle/aircraft identification. Over 99 percent of all targets engaged were hit; only 4 targets were missed during the study. The number of targets engaged decreased during the study and the time to engage targets increased.

No statistical analysis of the effects of test conditions was made concerning their effect on crew performance and endurance due to "limitations in the sample size and the confounding of many variables" (Glumm, 1988, p. 4). The confounding included the effects of attrition. Glumm reported that the data obtained in the study indicated that crews dressed in MOPP 4 CW-protective combat clothing and performing in temperate climatic conditions "will have difficulties sustaining effective operations in the M1 tank system under NBC conditions for extended periods of time" (Glumm, 1988, p. 39). The materiel and procedural variables had little or no effect on crew performance or on endurance.

Psychological Effects. Munro, Rauch, Banderet, Lussier, Tharion, and Shukitt (1987) reported the psychological effects of the IRONMAN test. Four questionnaires were administered: (1) Environmental Symptoms Questionnaire (ESQ); (2) Clyde Mood Scale (CMS); (3) Crew Atmosphere Scale (CAS); and (4) Cognitive Strategies Questionnaire (CSQ). They found that the crewmen who withdrew reported more intense symptoms than those who did not voluntarily withdraw. Munro et al. (1987) found that symptom intensity as measured by the ESQ increased during the test. When comparing pre- and post-test symptoms, thermal symptoms showed a 600 percent increase; respiratory, musculoskeletal, neurological, and gastrointestinal symptoms showed a 300 500 percent increase; and fatigue showed over a 200 percent increase. Mood changes as measured by the Clyde Mood Scale were more prevalent than symptom changes. There was a general deterioration of mood which was indicated by two patterns. The intensity of

sleepiness, dizziness, and unhappiness increased while aggressiveness, friendliness, and clear thinking decreased.

b. Sustained Operations of Mechanized Infantry

Mitchell, Knox, and Wehrly (1987) and Headley, Brecht-Clark, Feng, and Whittenberg (1988b), reported the results of field tests of mechanized infantry personnel wearing CW-protective combat clothing. Thirty-six soldiers served as subjects. The test was divided into two phases. Phase IA involved four Bradley Infantry Fighting Vehicles (BIFV) with a vehicle team (commander, gunner, and driver) and a six-member dismount team. The subjects received 23 hours of MOPP 4 acclimation and training. The test was conducted wearing MOPP 1 and MOPP 4, and was conducted over a two week period. The test was designed for 72 hours with each 24-hour period involving a 6-hour combat scenario (test course of 3.9 miles with 13 fixed stations for combat-related tasks) which was repeated three times. At the end of each scenario, decontamination was conducted, a meal consumed, and MOPP 4 removed for 45 minutes. The fourth 6-hour period was scheduled for sleep. Two crews completed 59 hours; the other two crews had mechanical and administrative problems. There were five casualties, three dismount team members and two vehicle team members, out of 35 subjects. The casualties occurred between 13 and 48.4 hours elapsed time (average 30.8 hours). Only one casualty was removed due to a high rectal temperature; he was asymptomatic and later he returned to the study. Performance data comparing MOPP 1 and MOPP 4 indicated that 80 percent of the 106 tasks were not different. For 18 percent of the tasks, MOPP 4 had a longer time.

For Phase IB, two BIFV and one M113A1 armored personnel carrier were scheduled to operate 72 hours in a continuous endurance run with the subjects wearing MOPP 4 without decontamination, meals or sleep. The BIFV crews remained in the test for 31.4 and 33.3 hours and the M113A1 crew remained in the test for 37.9 hours (Headley et al., 1988b). During this time there were 11 casualties out of 26 subjects; none was due to high rectal temperature. Nine of the casualties were members of the dismount team and two were members of the vehicle team. The casualties occurred between 8 and 31.5 hours (median, 14 hours; average, 18.9 hours).

It is interesting to note that rectal temperature is a poor predictor of the staytime of mechanized infantry under warm conditions. About 14 percent of combat infantry who were fully acclimatized in MOPP 4 prior to the start of the study became casualties in a 5-hour work/1-hour rest cycle during a 72-hour test in MOPP 4. In a continuous

operation, 42 percent became casualties within 32 hours of a 72-hour test. At that time the combat force was determined to be ineffective due to casualties. The authors fail to discuss the implications of the number of casualties in Phase IB during mild to moderate climate conditions.

c. Sustained Operations of Armor Crews

Knox, Simmons, Christiansen, and Siering (1987) and Headley, Brecht-Clark, Feng, and Whittenberg (1988b) reported the results of field trials of armor personnel wearing CW-protective combat clothing (MOPP 4). The subjects consisted of 27 soldiers whose MOS was 19E (M60 crewman) or 19K (M1 crewman). The experimental design was a repeated measures design involving two platoons, each participating on separate days in a 24-hour, MOPP 0 (BDU) and three 48-hour, MOPP 4 tactical scenarios. The first condition, Phase 0, consisted of BDU which was followed by three phases of MOPP 4 with two iterations of each phase. The scenario required a platoon of four tanks to defend a ridge line against an opposing force. Phase I was a baseline condition in which two platoons wore MOPP 4; Phase II replicated the materiel and coping strategies described by Glumm (1988); and during Phase III, the subjects wore MOPP 4 combined with microclimate cooling vests in the M60A3 and overpressure in the M1A1. Four soldiers were scheduled to man each tank but for some tests only three soldiers were available. Continuous operations were programmed for 48 hours. Each vehicle became combat ineffective when two of the crew members left.

The subjects were acclimatized to MOPP gear for 6 hours. The BDU condition was conducted for only 11 of the planned 24 hours due to delays in the study. Headley et al. (1988b) reported that "All crews of both platoons were able to complete these runs, and they sustained no casualties."

The results of the MOPP 4 trials indicated that none of the crews was able to complete the 48 hours of continuous operations under the hot environmental conditions. The tank crews in MOPP 4 lasted from 3.3 to 16.6 hours (Headley et al., 1988b). Of the 73 "tank crewmen starts," i.e., a trial during an MOPP 4 iteration, 32 individuals (44 percent) were casualties and 17 of the 19 "trial starts" ended as combat ineffective tank trials. Further, results reported in the abstract only, by Knox et al. (1987) indicated that tank crews were able to continue only for an average of 6 hours without microclimate cooling vests. One crew performed for 16.41 hours with cooling and one crew without cooling and wearing MOPP 4 completed 15.01 hours, but the WBGT recording inside the

tank was a maximum of about 32°C. Seven crew members either passed out or were casualties due to high core temperatures. Twenty-six additional crew members elected to leave; the symptoms included dizziness, headache, nausea, stomach ache, eyes hurt, knee popped, lightheaded, and sick. Headley et al. (1988b) reported that lack of consistancy prevented performance data analysis.

Knox et al. (1987) concluded there were no major differences between MOPP 4 and MOPP 4 with "fixes" in terms of physiological performance of subjects. No statistical analyses were performed due to the small number of crews and the number of conditions tested.

A study by Tharion, Rauch, Munro, Lussier, Banderet, and Shukitt (1986) examined the psychological factors which limit the endurance of armor crews operating in chemical protective combat clothing. Twenty-seven male soldiers assigned to six four-man crews and one three-man crew served as subjects. The experimental design consisted of three treatment conditions (MOPP 4, FIX, and SUPER) and a control. Each crew participated in a standard armor field test under the four conditions. The data from the SUPER condition was not used during the analysis. The FIX condition permitted eating while in MOPP 4 and the subjects were trained to use coping strategies designed to mitigate stress. Crew members who voluntarily withdrew or were removed by the medical monitor were designated as casualties; the remaining crew members were designated as survivors. A psychological test battery which consisted of the ESQ, CMS, State Anxiety Questionnaire, and Crew Atmosphere Questionnaire, were administered pre-test and post-test and at six hour intervals during the field test.

For MOPP 4, casualties exhibited greater depressive tendencies and lower self-motivation than survivors. On the Clyde Mood Scale, casualties reported more intense feelings of sleepiness and dizziness when compared to survivors.

d. Sustained Operations of Artillery Crews

As part of the P^2NBC^2 program, Headley, Brecht-Clark, and Whittenberg (1988a); Headley, Brecht-Clark, Feng, and Whittenberg (1988b); Rauch, Banderet, Tharion, Munro, Lussier and Shukitt (1986); and Knox, Mitchell, Edwards and Sanders (1989), reported different aspects of a field test designed to determine the ability of artillery crews to sustain combat operations in MOPP 4. Four 9-man howitzer crews were scheduled to fire 250 rounds in 72 fire missions over 24 hours. One crew was dressed in the BDU and three crews in MOPP 4. Data collected included firing and endurance data; psychological

test data as well as physiological data were collected. A crew was declared combat inoperative when the crew dropped below five. All crews were trained on the tasks and the three MOPP 4 crews had 3 hours of CW-protective combat clothing habituation prior to the test.

The crew dressed in BDU completed the scenario, but the three MOPP 4 crews lasted 3.8, 1.9, and 2.1 hours. Two of the MOPP 4 crews were terminated due to five casualties while the third MOPP 4 crew was terminated after the loss of the Chief of Section (3rd casualty in this crew) due to vomiting. The termination protocol specified that the crew would be terminated if the chief of section was lost. All casualties were dressed in MOPP 4; the earliest casualty occurred after only 82 minutes. The majority of the symptoms of the casualties were dizziness, nausea, and headache. The average dry bulb temperature was 90°F. Table III-12 summarizes the data from the test.

Table III-12. Artillery Test, BDU/MOPP 4

	Crew			
	1	2	3	4
MOPP	0	4	4	4
Elapsed Time	19 hr 21 min[a]	3 hr 45 min	1 hr 53 min	2 hr 8 min
No. of Fire Missions	66	15	6	4
No. of Rounds	228	66	33	23
No. of Casualties	0	5	5	3
Time toFirst Casualty	N/A	160 min	82 min	98 min

[a] Exercise temporarily halted for administrative reasons, restarted, and 66 of planned 72 fire missions conducted (Headley et al., 1988).

Knox, Mitchell, Edwards, and Sanders (1989) reported on the physiological data recorded during these field tests. The highest mean and the highest maximum rectal temperature recorded for the BDU group was 37.6°C and 38.6°C, respectively, for the gunner. Only one crew member, the assistant gunner of crew 2 (MOPP 4), was withdrawn by the medical team due to his core rectal temperature exceeding the criterion of 39.2°C. For crew 2 (MOPP 4) seven, for crew 3 (MOPP 4) six, and for crew 4 (MOPP 4) five of the nine crew members had rectal temperatures which equaled or exceeded the core temperature of the highest observed for the BDU group. All crew members who

voluntarily withdrew had mildly elevated temperatures indicating some heat storage. The heart rate data were unusable due to instrumentation problems. The authors stated that the physiological measures were not clear predictors of the withdrawal. They hypothesized that the crew members withdrew because they were unable to cope with thermal discomfort and related symptoms and still perform the assigned tasks.

Comparisons of first round times and interround intervals for a 2-hour period for crews 1 (BDU) and 2 (MOPP 4) indicated significant performance deficits for the MOPP 4 crew. In addition, the MOPP 4 crew was unable to sustain consistent performance for the 2-hour period.

The results of the study indicated that the ability to perform howitzer fire missions in MOPP 4 in a hot environment is quickly degraded due primarily to the voluntary withdrawal of crew members. It would be interesting to have calculations of watts produced and dissipated under the experimental conditions. Hinch (1982) used the computer model developed by Goldman and associates at the U.S. Army Research Institute for Environmental Medicine to calculate that a heavy workload would produce 400 kilocalories/hour (KCAL/hr). The accumulation of 80 KCAL is considered safe but heat stress symptoms occur when 120 KCAL of undissipated heat in the body accumulates. On the other hand, most individuals will be uncomfortable when 80 KCAL accumulates.

Headley et al. (1988a) noted that the performance decrement produced by MOPP 4 "might be decreased somewhat by more training in the ensemble. Training seems to be one necessary facet of a MOPP 4 regimen, not just for habituation, but for learning 'how to conduct business' while wearing the full ensemble. Properly trained and accustomed soldiers would constitute one important fix toward flight while in MOPP 4 versus 'fighting' the MOPP 4. Most tasks can be performed while wearing the ensemble, and it is during training sessions and not on the battlefield that the soldier should learn how to work while attired. Soldiers often improvise ways to perform their duties, and thus a learning effect will exist for many tasks. An additional benefit of training is that one can experience the discomfort involved in wearing the gear, and can gradually habituate to the suit . . ." (Headley, Brecht-Clark, and Whittenberg, 1988a, pp. 9-10).

Rauch et al. (1986) reported the results of psychological tests conducted as part of the field test. Each subject was administered a psychological test battery consisting of the following three tests: (1) Environmental Symptoms Questionnaire (ESQ) which assessed psychological perceptions of physiologically based systems during exposure to extreme environmental conditions; (2) Clyde Mood Scale (CMS) which assessed mood changes;

and (3) State Anxiety Inventory (SAI) which assessed the level of anxiety at a particular time. The tests were administrated to all sections prior to the start of the field test and at 6-hour intervals during the test.

Rauch et al. (1986) defined medical casualties as subjects who voluntarily withdrew or who were withdrawn by the medical team. There were no medical casualties in the BDU group but there were 13 medical casualties for the three sections dressed in MOPP 4. The remaining 14 subjects ended their participation in the study when their section was classified as combat ineffective due to removal of other section members as medical casualties. For the purpose of analysis, the subjects in the three sections dressed in MOPP 4 were assigned to two post hoc groups--casualties (N = 13) and survivors (N = 14). The pre-test and post-test scores on the three psychological tests were analyzed to assess differences between the two post hoc groups. Significant differences were found between the casualties and survivors in the intensity of the following nine perceived symptoms computed from the ESQ test scores: short of breath, hurts to breathe, muscles tight, headache, faint, warm, body numb, nose stuffed up, and concentration off. Significant differences were also found for the following four CMS factors: clear thinking, fatigue, friendliness, and dizziness. The casualties also reported a greater tendency to "tire quickly," to perceive their "duty position to be less stressful" and to "volunteer for the study because of the challenge."

It is interesting to note that the survivors reported no significant change in symptom intensity as a result of performing the artillery mission in MOPP 4, but the casualties reported significant changes in symptom intensity.

The study failed to analyze the differences between casualties and survivors for pre-test scores; the analysis was concerned only with post-test scores. If pre-test differences are found, one would be able to predict potential casualties and provide them additional training.

Rauch, Munro, Tharion, and Banderet (1986) combined the data from the Rauch et al. (1986) study with data from subjects from sustained military field operations by armor and infantry personnel. A total of 77 cases consisting of 42 individuals in the casualty group and 35 in the survivor group was used to perform two stepwise discriminant analytic techniques on post-test data. The purpose of the analysis was to specify one linear combination of subjective symptoms and one linear combination of coping strategies that maximized the difference between casualties and survivors. The results indicated that the symptom-based classification routine correctly identified

94 percent of the subjects as members of their respective group. The coping-based classification correctly identified 98 percent of the cases.

3. Heat Stress Field Trials

a. XM1 Tank with Auxiliary Cooling

A U.S. Army field trial investigated the effects of auxiliary cooling in preventing heat stress in an XM1 tank (Goldman and Staff, 1981; Toner, White, and Goldman 1981). Two crews of heat-acclimated tank crewmen, dressed in the standard Combat Vehicle Crewman (CVC) uniform plus configurations of CW-protective combat clothing (MOPP 3 and 4), participated in a 6-day study which evaluated heat stress in the XM-1 tank. The experimental conditions were as follows:

Day 1	CVC uniform	Hatch open ventilated
Day 2	CVC and MOPP 3	Hatch open ventilated
Day 3	CVC and MOPP 4	Hatch open ventilated
Day 4	CVC and MOPP 4	Hatch closed unventilated
Day 5	CVC and MOPP 4 w/auxiliary cooling	Hatch closed unventilated
Day 6	CVC and MOPP 4	Hatch closed unventilated.

Heart rate and skin temperature (ts) and rectal temperature (tre) were measured. A moderate level of activity was maintained (one 3-5 minute fire mission performed every 30 minutes). The exposure was limited to 3 hr/day. During days 1-3 both crews completed the scenario. The scenario was not completed on either day 4 or 6; the gunner terminated the trial after 80 and 124 minutes, respectively, and errors were observed among the crews within 30 minutes. The crew estimate that their ability to perform ranged between 20 and 75 percent on these days.

Under MOPP 4 conditions and using water-cooled vests, crews completed the 3- hour scenario. The results clearly indicated that the vest substantially reduced heat stress due to wearing CW-protective combat clothing.

b. Vehicle (M113)/No Vehicle Pre-Assault

A field trial conducted in a tropical environment (Panama, C.Z.) was concerned with heat stress and performance (Hanlon, Jones, and Merkey, 1982). The purpose of the field trial was to determine the effects of vehicle/no vehicle pre-assault, male/female

differences, and combat clothing (U.S. MOPP 4/U.K. MOPP 4). The investigators were unable to use time as the dependent variable as planned and the proposed repeated measures design was discarded. The results of the field trial indicated that personnel enclosed in an M113 personnel carrier experienced the most severe heat stress. Some evidence was presented that indicated differences between male and female tolerance to heat stress as measured by core temperature (females were lower), but the limited number of subjects, 5 males and 5 females, prevented statistical analysis of the data.

c. Sustained Aviation Operations

Mitchell, Knox, Edwards, Schrimsher, Siering, Stone, and Taylor (1986) conducted a field study to determine the physiological, psychological, and operational effects of sustained aviation operations in CW-protective combat clothing. Six male aviators were evaluated individually during a period of 6 continuous days of testing in a hot, humid environment. The subjects were in MOPP 4 for about 12 hours and MOPP 1 for about 12 hours for each 24 hour period. Four flight missions of 90 minutes each (one mission profile) were scheduled to be flown each day for each subject for a total of 36 mission profiles. The flights included low level operations, nap-of-the-earth flight, confined area operations, instrument approaches and other tactical operations. Additional flight maneuvers [i.e., heading, altitude, air speed, and time (HAAT) and precision control] which tested pilot performance were recorded on an inflight recorder. Microclimate cooled vests (both air and liquid) were worn for 16 of the 36 mission profiles; no vests were worn for 20 mission profiles. For the latter 20 mission profiles, a total of 12 profiles were terminated due to medical problems prior to completing the four flight missions. Five of these occurred on the first day due to nausea and fatigue. During this period, the subjects also indicated an inability to concentrate. Without cooling vests, 60 percent of the missions were terminated. The physiological results indicated that a cockpit temperature of 29°C resulted in the subjects exceeding a rectal temperature of 38°C more than 50 percent of the time. This rectal temperature has previously been associated with a threshold for decreased performance (Grether, 1973). These findings are supported by previous studies concerned with predicted and observed upper boundaries of safe environmental temperatures while wearing CW-protective combat clothing and performing low rate metabolic activity (Toner, White, and Goldman, 1981; Berlin, Stroschein, and Goldman, 1975).

The overall ratings and comments from safety pilots indicated that all subjects could fly safely in MOPP 4 and generally perform to Army Standards. Low performance ratings were noted on nap-of-the-earth (NOE) portions of the flights when the subjects were

navigating. Performance on the HAAT and precision control maneuvers were not affected by heat stress. One important finding was that only about 5 liters of water intake per 24 hours was required.

d. Helicopter Control

Hamilton, Folds, and Simmons (1982) conducted a field trial to determine the ability of U.S. Army helicopter pilots to safely and effectively control the aircraft while wearing CW-protective combat clothing. In a hot environment, six Army aviators performed a precision flight profile, a lateral hover and a 50-foot hover, on 3 successive test days with a day of rest between flight days, while wearing the following clothing: U.S. Army aircrew chemical defense ensemble (MOPP 4), the United Kingdom aircrew chemical defense ensemble and the U.S. Army standard flight suit. The six permutations of the order of the three suits were used, i.e., the order of wearing the three suits differed for each subject. One subject flew in the morning and a second subject flew in the afternoon. A mission consisted of 4 hours of flying which were broken into two 2-hour blocks.

The precision maneuver consisted of heading, altitude, airspeed and time. The maneuver was repeated in nine successive trials (one iteration). At the beginning of each trial, the safety pilot read a set of situations to the subject which consisted of the following four parameters: heading, one-eight-zero; altitude, 900 feet; airspeed, 80 knots; time, 20 seconds. For trials one, two, and three the altitudes and airspeeds were constant and the heading changed in a multiple 5 degrees for each trial. For trials four, five, and six, the airspeed was constant while heading and altitude (a multiple of 20 feet) changed. In trials seven, eight, and nine, all three parameters changed (airspeed in a multiple of 5 knots). Following the precision profile, the lateral hover and 50-foot hover were performed after the safety pilot repositioned the aircraft. This cycle was repeated for 1 hour. After 1 hour the aircraft lands, and the subject drinks water in the aircraft. The procedure is repeated for an additional hour after which the aircraft lands, the subject leaves the aircraft, and drinks water while the aircraft is refueled (15-20 min). The 2-hour procedure is repeated to complete the 4-hour flight scenario.

Automated performance data on the precision maneuver parameters were collected for only four subjects; recorded performance data were not available for two subjects due to equipment malfunction. Only one of four subjects completed the six possible iterations in the U.S. ensemble, but three of four completed the iterations in the U.K. ensemble; the six

iterations were completed by each subject in the standard flight suit. The average median errors and percent accuracy degradation (D_A) scores for the standard flight suit, the U.S. ensemble and the U.K. ensemble are presented in Table III-13.

A two-factor, repeated measures analysis of variance (ANOVA) was computed: the median SD heading error was the only significant variable ($P = .01$).

Table III-13. Average Median Errors and Average Median Standard Deviation (SD) for Standard Flight Suit, U.S. Ensemble and U.K. Ensemble

	ST	U.S.	D_A^b	U.K.	D_A^b
$\bar{X}$ Median Heading Error	1.63°	2.02°	– 24%	1.78°	– 9%
$\bar{X}$ Median Airspeed Error	1.83K	2.19K	– 20%	1.95K	– 7%
$\bar{X}$ Median Altitude Error[a]	--	--		--	
Mean Timing Error	0.93	1.08	– 16%	1.58	– 70%
$\bar{X}$ Median SD Heading Error	1.47°	1.58°	– 7%	1.44°	+ 2%[c]
$\bar{X}$ Median SD Airspeed Error	1.27K	1.86K	– 46%	1.69K	– 33%
$\bar{X}$ Median SD Altitude Error[a]	--	--	--	--	--

[a] Not available--equipment failure.

[b] Calculated from data of Hamilton et al., 1982.

[c] Advantage for U.K. ensemble.

Two subjects wearing the U.S. ensemble were terminated due to heat stress but their performance immediately prior to termination was satisfactory. Hamilton et al. concluded that there were no practical differences between performance while wearing the standard flight suit and the U.S. and U.K. ensembles.

Hamilton, Simmons, and Kimball (1982) conducted psychological tests on these same six Army aviators before and after flights. Tests were also conducted on non-flight days to provide a no-flight baseline. The tests consisted of the following subtests from the Performance Assessment Battery (PAB) developed by Walter Reed Army Institute of Research: Encode/Decode, Target Recognition, Logical Reasoning, Serial Math, and Reaction Time (four-choice). Mood scale and Feeling/Tone questionnaires were used to assess mood and feeling.

The raw scores on the subtest were converted into a percent of change from baseline (pretest) as follows:

$$\frac{A-B}{B} \times 100$$

where

B is the pre-test score

A is the post-test score.

A randomized block ANOVA with replicates was used to analyze the data. None of the subtests was statistically significant. The self-report of mood also failed to show significant differences.

Next, the data were organized, irrespective of clothing conditions, based on physiological responses into three categories, which reflected the degree of heat stress (i.e., slight, moderate, and severe). Using this procedure there were three cases of severe heat stress, seven cases of moderate heat stress, and six cases of slight heat stress. No statistical comparisons were made from these data but the trends indicated that severe heat stress impairs performance while slight heat stress improves performance.

4. Other Field Trials and Field Training Exercises

a. Aircraft Ground Crews

Hinch (1982) analyzed field tests concerned with the performance of airbase personnel in CW-protective combat clothing. According to Hinch previous tests have shown that airmen in CW-protective combat clothing can accomplish virtually all normal tasks but the time to accomplish the tasks is longer and in some cases the error rate is increased. Heat buildup in the body limits the length of work time. These factors combine to reduce job performance of airbase personnel dressed in CW-protective combat clothing.

Table III-14 summarizes the results of a field test which involved two ground crews performing quick turns on F-4 aircraft while wearing the following three combinations of CW-protective combat clothing: Condition A: M17A1 mask, butyl rubber gloves and booties; Condition B: A plus overgarment and M6A2 hood (MOPP 4); Condition C: B plus leather gloves. The tests were performed in B first (MOPP 4), then A and C, respectively.

The impact of different combinations of CW-combat clothing were confounded by the fact that performance improvements occurred during the test due to increased task proficiency and to adaptation to CW-protective combat clothing. Since the results are

presented as "proficiency loss," evidently the task performances were compared to a baseline condition but these data were not presented. Hinch reports that potential proficiency improvements are possible by training in CW-protective combat clothing, but no data were presented to support this statement.

Table III-14. Proficiency Loss in F-4 Quick Turn Tasks

Task	Proficiency Loss		
	Condition		
	A	B	C
	percent		
Safe Gun	28	43	48
Back Aircraft	6	23	17
Stray Voltage Check	27	38	48
Ammunition Loading	24	41	36
External Tank Installation	43	51	50
Aim-9 Missile Load	20	20	32
Aim-8 Missile Load	44	50	51
Refuel	19	28	20
Complete F-4 Quick Turn	27	42	40

b. Aircrew Maintenance Tasks

Under simulated chemical warfare conditions, aircraft maintenance technicians will be required to wear CW-protective combat clothing while preparing aircraft for the next mission as well as while repairing aircraft. The general effects of the bulky CW ensemble are well known; it restricts movement, vision, communications, and endurance. Wearing the CW ensemble has also been found to increase the time required to perform some tasks. Technicians will have to work more slowly and carefully to prevent compromising the ensemble. Air Force planners and field commanders need to know the capabilities and limitations of maintenance technicians under CW conditions. They must know which maintenance tasks can be accomplished and the time needed to accomplish them, which tasks can be deferred, and which tasks are impossible to perform while wearing CW-protective combat clothing. They also need to know the actions such as training,

equipment redesign, policy or procedure changes, and workaround procedures required to reduce the impact of wearing the CW ensemble.

In order to provide these data, the United States Air Force conducted a four-phase field study to evaluate the impact of CW-protective combat clothing on the performance of maintenance tasks. The objectives of the four phase field study were:

> 1. To develop a methodology for determining the capabilities of maintenance personnel to perform critical tasks in chemical defense protective clothing;
> 2. To determine how task times and sortie-generation capabilities are impacted by wearing the chemical ensemble;
> 3. To identify any deficiencies in the present equipment, tools, and procedures;
> 4. To measure the effects of selected experimental manipulations on the capabilities of maintenance personnel to perform maintenance in chemical environment; and
> 5. To develop techniques to improve the ability of maintenance units to accomplish their mission in a chemical environment.
>
> --Shipton, Chenzoff, Joyce, Deibel, and Weimer, 1988 p. 2

Phase I consisted of developing job performance measurement methodology to measure maintenance technicians' job performance under CW-conditions. During Phase II 26 maintenance tasks for the F16 aircraft were selected based on the following criteria: (1) involved a system component with a high failure rate; (2) completing the task is critical (required) to completing an aircraft combat sortie; (3) time required to complete the task was 1 hour or less; (4) the task requires fewer than five people; (5) the task is representative of tasks for other types of aircraft (Shipton, Beilstein, Chenzoff, Pitzer, and Joyce, 1988). Most of the maintenance tasks were "remove and replace tasks."

Phase II was conducted at Hahn Air Base, Germany. A total of 40 skilled technicians participated in the field study, all of whom had experience with the respective maintenance tasks. Most tasks were performed four times--twice in fatigues and twice in the chemical defense ensemble. Each task was performed by two technicians; each of whom performed the task once in fatigues and once in MOPP 4. The first and fourth iterations were performed in fatigues and the second and third in MOPP 4. Six tasks were performed by teams of two or more technicians.

A number of maintenance problems were encountered by the technicians while wearing MOPP 4. All subjects wore the MCU-2/P mask, a replacement for the M-17 mask, and either 7-mil or 14-mil gloves instead of the standard 22-mil glove. Reports by the subjects concerning the MCU-2/P masks indicated that it was an improvement over the M-17 mask. They reported that it was more comfortable and permitted a wider field of view. In 17 cases, the plastic outsert, which protects the face plate, fogged up and restricted the subjects' vision. A majority of the subjects preferred the new gloves over the 22-mil glove. The new gloves were reported to provide better tactility and finger dexterity, but there were some compromises which ranged from small punctures to large cuts or holes. The CW ensemble jacket was compromised nine times.

The subjects were requested to rank the tasks that would be most severely impacted by wearing CW-protective combat clothing. There was "nearly complete agreement" about the seven tasks that would be most severely impacted, but considerably less agreement among the remaining 19 tasks. The seven tasks for which there was agreement concerning the impact of CW-protective combat clothing were as follows: (1) drop tank build-up; (2) engine rollback and replacement; (3) integrated servoactivator; (4) integrated drive gearbox; (5) jet fuel starter; (6) ejection seat; and (7) environmental control system turbine.

The average percent time degradation due to CW-protective combat clothing was 30.7 percent. The authors discussed recommendations for modifications to aircraft and to aerospace ground equipment (AGE) design, to tools, and to the way tool requirements are determined. The authors suggested that if these recommendations are adopted, the impact on maintenance due to wearing MOPP 4 would be reduced.

Following Phase II, Shipton, Beilstein, Chenzoff, Pitzer, and Joyce (1988) reported the need for the following two types of training: (1) general maintenance practices, and (2) how to maintain the integrity of CW-protective combat clothing while performing maintenance. They reported that poor or inappropriate maintenance practices exacerbated problems encountered in MOPP 4. They also reported a need for increased awareness of the role of CW-protective combat clothing in protecting the maintenance technician from hazardous chemicals. The CW ensemble was compromised during the performance of 19 of the 26 tasks. Many of these compromises could have been avoided. The authors recommended the following training:

- Training in handling sharp objects while wearing rubber gloves.
- Improved annual training on the wear and care of the CW ensemble.

- Increased use of the CW ensemble during real-world situations, such as phase inspections.
- Use of training aircraft in field training detachment (FTD) for practicing tasks in the CW ensemble. Periodically, practice different tasks in the CW ensemble.

They also recommended that all kinds of aircraft maintenance tasks should be included in chemical ensemble exercises to evaluate the technicians' ability to function under simulated wartime conditions, to determine the limitations that exist and to evaluate improvements gained from practice.

> Phase III had the following goals:
>
> 1. Revise the methodology developed in Phase I and used in Phase II, as necessary to overcome the problems encountered.
> 2. Develop alternate or workaround procedures that will reduce the impact of the chemical warfare environment on performance.
> 3. Collect data on the performance of the selected tasks at Hahn AB.
> 4. Examine 10 tasks identified in Phase II as severely impacted, to identify the reasons for difficulties encountered in performing the tasks.
> 5. Test the task evaluation scheme developed in Phase II.
> 6. Assess the impact of the chemical warfare environment on the performance of the selected tasks.
>
> --Shipton, Chenzoff, Joyce, Deibel and Weimer, 1988 p. 3

Phase III was conducted at Hahn AB, West Germany during June and July 1987. Ten F-16 maintenance tasks, which were determined during Phase II to be severely impacted by wearing CW-protective combat clothing, were selected for further study. These tasks represented a broad range of the maintenance tasks performed by F-16 maintenance technicians. Table III-15 lists the 10 tasks, the number of times the tasks were performed, and the number of technicians required to perform each task. All tasks were performed in the full CW ensemble.

Table III-15. Phase III F-16 Maintenance Tasks

Tasks	No. of Times Performed	No. of Technicians
1. 370 Gallon Drop Tank Build-up	4	2
2. Main Generator/Constant Speed Drive Remove and Replace	5	2
3. Ejection Seat Raise and Tilt, Rotate and Lower	6	2
4. Jet Fuel Starter Remove and Replace	6	2
5. Angle-of-Attack Transmitter Remove and Replace	6	1
6. Nosewheel Steering Feedback Potentiometer Remove and Replace	6	1
7. Environmental Control System Turbine Remove and Replace	6	1
8. Jettison Remote Interface Unit Remove and Replace	6	1
9. Fire Control Radar Antenna Remove and Replace	6	1
10. Hydraulic Pressure Transmitter Remove and Replace	6	1

The following interventions were developed to reduce the impact of wearing CW-protective combat clothing: training, workarounds, tool modifications, and alternative policies and procedures.

Nine of the 10 tasks were performed six times each by maintenance technicians wearing CW-protective combat clothing and the interventions were tested during the fifth and sixth iterations of the task (Task 2, Main Generator/Constant Speed Drive Remove and Replace was performed only five times; the first iteration was not completed). Due to the length of time to perform Task 1, the 370-Gallon Drop Tank Build-Up task, it was performed only four times with the interventions performed on the third and fourth iterations.

The subjects were 14 Air Force F-16 maintenance technicians with Air Force specialty codes appropriate to the tasks that they performed. Eleven of the subjects were 5-level technicians (less experienced but fully qualified) and three subjects were 7-level technicians (more experienced). The technician's experience ranged from 3 months to 5 years 2 months on the F-16 aircraft (average 26 months). The average time the subjects had spent in the CW jacket, pants, and boots was 518 hours, but an average of only 174 hours and 172 hours had been spent in the CW gloves and CW mask respectively.

The temperature ranges during Phase III were between 53° and 84° F (12° and 29° C). The task and timing of task performance were temporarily stopped if early signs of

heat stress were detected. The technicians were permitted to remove the mask and hood and to have a brief rest period.

During the last two trials for each task, the following four interventions were introduced: (1) training; (2) workaround procedures; (3) modification to aircraft, aerospace ground equipment (AGE), and tools; and (4) changes to the Job Guides. These interventions were introduced to mitigate the performance degradation caused by wearing CW-protective combat clothing and to reduce compromises to the CW ensemble. The training interventions consisted of providing the subjects with training handouts concerning how to work safely in the CW ensemble. Task-specific training handouts were also given to some subjects. The non-training interventions listed above were described in detail for each task.

The times to perform each task for each iteration were recorded by two observers. The observers also recorded observations concerning dropped items and difficulties in performing the task. Following the completion of each task the observers checked the CW ensemble for integrity and the subjects were interviewed concerning task performance and the need for potential changes.

The observers also interviewed subject matter experts (SMEs). Prior to the test the SMEs had indicated that they believed many maintenance tasks were impossible to perform while wearing the CW ensemble. They also indicated that the time to perform the tasks would be prohibitive. The average time estimates by SMEs prior to the test exceeded by 390 percent the average time observed during Phase II when tasks were performed wearing the CW ensemble.

The time to perform each task for the first iteration was compared with the time to perform the last iteration. All tasks were performed faster during the final iteration. The improvement in performance time ranged from 30 percent to 63 percent with an average improvement of 52 percent. (For task 10, we chose to use the fourth iteration data since the fifth and sixth iterations were conducted under more difficult conditions than the first iteration.) These data are for a single technician for six tasks and a team of two technicians for four tasks.

There are several difficulties in interpreting these data. The data present clear evidence that task performance improves with repeated task performance while wearing the CW ensemble (training effect), but the training effect is confounded with interventions. Since no stable baseline was established for these subjects' task performance in fatigues

prior to testing in the CW ensemble, the effect of learning to perform the task, particularly with two-person teams, is confounded with the training effect of performing the task in the CW ensemble with the interventions, and with learning to work as a team for the two-person tasks.

In an attempt to parse these effects, Phase II average times and Phase II first times wearing fatigues were compared with Phase III first times and Phase III best times wearing the chemical ensemble. These comparisons are presented in Table III-16.

By examining Table III-16 one can see that the task times for three of the conditions are generally about the same. It should be noted, however, that for seven of the tasks the best CW times are equal to or less than the average fatigue times. The technicians wearing the CW ensemble had performed the task from four to six times while the fatigue times represent an average of two times performed by different technicians or different teams of technicians. Nine of the CW best times were less than the first fatigue times.

Table III-16. Comparison of Phase III CW Times and Phase II Fatigue Times (Data from Shipton, Chenzoff, Joyce, Deibel, and Weimer, 1988)

Phase II Tasks	Phase III CW 1st Time (min)	Phase III CW Best Times (min)	Phase II Average Fatigue Time (min)	Phase II 1st Time Fatigue Time (min)
1. 370 Gallon Drop Tank Build-up	614	296	279	244
2. Main Generator/Constant Speed Drive Remove and Replace	175	69	107	82
3. Ejection Seat Raise and Tilt, Rotate and Lower	85	53	44	58
4. Jet Fuel Starter Remove and Replace	63	23	47	73
5. Angle-of-Attack Transmitter Remove and Replace	197	71	96	127
6. Nosewheel Steering Feedback Potentiometer Remove and Replace	34	18	26	28
7. Environmental Control System Turbine Remove and Replace	71	50	53	83
8. Jettison Remote Interface Unit Remove and Replace	97	52	51	66
9. Fire Control Radar Antenna Remove and Replace	115	66	106	84
10. Hydraulic Pressure Transmitter Remove and Replace	31	12	12	16

These data reinforce the previous conclusions concerning performance decrements produced by the CW ensemble and concerning the benefits of practicing the task when wearing the CW ensemble. Since no data were collected concerning performing the task more than once in fatigues, one can not determine the percent performance decrement produced by the CW ensemble nor the extent to which task practice in the CW ensemble reduces the performance decrement.

The interventions reduced the number of compromises of the CW ensemble per task performance by 48 percent.

The results of the study indicated that the CW gloves are easily compromised when performing maintenance tasks. Thirteen of 14 technicians compromised the gloves during the test. The authors recommend that CW gloves for maintenance technicians be made of more durable material. The authors also recommended modification to the CW mask, suit, and overboot.

For each task, a number of problems were noted, e.g., tool mounting hardware, electrical connector, component positioning, space around the component, and technical manual job guide; the authors suggested solutions for each deficiency.

Of the three interventions, training appeared to have the greatest impact on increasing performance. The study concluded that Air Force maintenance technicians are not adequately trained in the proper way to don and doff the CW ensemble nor in the proper way to recognize hazards to the ensemble and how to avoid them.

c. Medical Unit Training Exercises

Carter and Cammermeyer (1985a) distributed questionnaires to 105 members of the 352nd Evacuation Hospital (rescue unit) following a unit training exercise performed while wearing MOPP 4. They found that 48 percent of the respondents had not worn MOPP 4 previously and another 23 percent had only worn MOPP 4 once. The time in MOPP for the exercise varied from 1 to 2 hours. Sixty-nine percent reported developing biopsychological symptoms while wearing MOPP 4. The most frequently reported symptoms were rapid breathing (N = 33, 48 percent); shortness of breath (N = 33, 48 percent); and loss of side vision (N = 33, 48 percent). Twenty respondents reported anxiety, 20 reported claustrophobia, and 20 reported visual disturbance (29 percent); 25 reported sweating (36 percent). The authors emphasized the need to provide appropriate training in the use of MOPP 4 equipment.

Carter and Cammermeyer (1985b) report case studies from five heat stress casualties which occurred during a mandatory annual 3-day simulated chemical warfare field training exercise (FTX) involving 195 members of the 352nd Evacuation Hospital. The most frequent biopsychological symptoms were excessive heat, rapid breathing, and shortness of breath. During the FTX they found that unit personnel expecting or receiving chemical casualties appeared to be under the most stress. They also found that unit personnel were less organized under the conditions of a simulated chemical attack, when compared to "conventional" warfare conditions.

Carter and Cammermeyer (1989) reported biopsychological symptoms of 182 military personnel participating in a simulated chemical defense warfare scenario, Wounded Warrior II, a major medical field training exercise conducted in 1985 at Camp Roberts, Cal. The simulated CW exercise lasted about 1 hour. Nineteen subjects (11 percent) failed to complete the 1-hour exercise. Thirteen of the 19 casualties (68 percent) reported shortness of breath, 13 reported rapid breathing (68 percent), 11 (58 percent) reported feeling hot and nine (47 percent) reported visual problems. For the entire sample, 58 percent reported feeling hot, 68 percent reported shortness of breath, 68 percent reported rapid breathing and 56 percent reported visual problems. Eighty-five percent of the total sample reported some biopsychological symptoms during the exercise. The subjects were unacclimatized reserve personnel with minimal prior training in MOPP 4. The casualties reported that managing the CW-protective combat clothing was the most difficult part of the exercise. The authors recommend that reserves be trained in CW-protective combat clothing for longer periods of time.

d. Shipboard CW Training Exercise

Garrison, Knudsen and Waskom (1982) reported a shipboard chemical warfare training exercise that could be used to evaluate readiness and level of training of ships involved in refresher training. Two ships, a tank landing ship (LST) and a frigate, were involved in the exercise which consisted of an attack with a chemical warfare simulant from a threat aircraft. Measurements were made of vapor and surface contamination and a personnel degradation study was conducted.

Following air attack on the LST, questionnaires were distributed to members of the survey and decontamination teams; 11 questionnaires were returned. The results indicated: (1) an adequate number of masks, suits and gloves, but not boots; (2) 8 of 10 surveyed were familiar with the chemical agent detector kit; (3) 5 of 11 were familiar with the symptoms produced by chemical agents; (4) visual problems were reported by 7 of the

11 team members; (5) 5 reported masks fogging problems and communication problems; (6) 2 reported breathing problems; (7) 4 of 7 reported that the suit caused problems in task performance; and (8) 6 of 7 reported they were extremely hot in CW suits.

Performance degradation in the Combat Information Center (CIC) was investigated. The task investigated was the interaction between a radarman and a chartman. The radarman observed the radar and called out positions while the chartman charted the positions to determine the location of the ship. Ten geographic positions were charted with both masked and unmasked personnel. For unmasked personnel, the average time required to chart a position was 2.6 minutes compared to 3.6 minutes with masked personnel; we calculated percent time degradation (D_T) = −38 percent. For unmasked personnel an average of 0.4 positions had to be repeated compared to an average of 3.5 repeated positions for masked personnel; we calculated percent accuracy degradation (D_A) to be −775 percent (almost an 8 fold increase in repeated messages). Performance degradation in the CIC was also investigated following an alerted attack on the LST. The average time to chart a position was 2.5 and 3.1 minutes for unmasked and masked personnel, respectively (D_T = −24 percent); the average repeated number was 0.5 and 3.4 for unmasked and masked personnel (D_A = −580%). The findings essentially replicated the findings of the earlier attack.

e. Amphibious Shipboard CW Exercise

Carson, Moskal and White (1989) reported a two phase approach to determine the degradation of tasks performed shipboard during amphibious operations which resulted from wearing CW-protective combat clothing. The first phase involved identifying mission critical tasks, the perforance of which was expected to be degraded during CW conditions. The second phase involved collecting data during a Navy amphibious exercise, Kernel Blitz, which was conducted off the coast of Camp Pendleton, Cal., August 1986.

Phase I involved the use of subject matter experts to: (1) identify a CW-threat scenario; (2) determine critical combat missions; (3) compile a list of tasks; (4) determine critical tasks; and (5) select 5 tasks for detailed analysis. The following tasks were selected:

1. Use of fog agents, extinguishing agents or water
2. Engage/disengage water
3. Maintain/replace equipment

4. Fuel/defuel aircraft
5. Splice line

During Phase II, observations of task performance in CW-protective combat clothing were conducted and the subjects were interviewed. The five tasks selected in Phase I were not scheduled to be performed during the exercise so SMEs selected the following watch stations:

Bow Thruster
Bow Thrust Operator
Line Handler, Bow Ramp
Petty Officer in Charge, Stern Anchor
Block Line Handler
Line Petty Officer, Boat Deck
Line Handler, Boat Deck
Flight Deck Officer
Flight Deck Crewman
Landing Signalman, Enlisted
Two Line Handlers, Well Deck

The tasks were performed on a Tank Landing Ship (LST) and on an Amphibious Transport Dock Ship (LPD). Each subject was observed by a Navy SME and by an experimenter who later interviewed the subjects. Thirteen Navy enlisted men served as subjects; each subject performed all tasks associated with his watch station. For 9 of the 13 subjects, task performance was observed on at least one BDU trial and one MOPP 4 trial; generally the BDU condition preceded the MOPP 4 condition. For four subjects, no trials were conducted in BDU, but one or two trials were conducted in MOPP 4. After each trial a questionnaire was administered using an interview format.

Most of the observations made by SMEs and researchers during MOPP 4 trials related to problems with communications or problems caused by CW-protective combat clothing. Communications were described as distorted (10 observations), unsuccessful (4 observations), repeated (3 observations), and hand signals had to be used (2 observations). In comparison to the 19 negative comments concerning communications in MOPP 4, only 4 negative observations were made concerning communications

during BDU trials. The CW ensemble negative observations involved the masks (12 observations), the two-piece overgarment (11 observations), the helmet (10 observations), gloves (8 observations) and boots (4 observations). Two line handlers began to pass out due to heat while one phone talker experienced drowsiness.

Task performance times in BDU and MOPP 4 were collected by the experimenters but variability prevented analysis of the data. There was no attempt to reach a stable performance level in BDU before the tasks were performed in MOPP 4. In some cases the data indicated the effects of learning to perform the tasks.

The questionnaire data indicated that the subjects experienced difficulty with communications while performing the tasks. No communication problems were reported by 12 of 12 responding after BDU trials. Communciation problems were reported by 12 of 12 responding after the first trial in MOPP 4. Visibility problems were reported after performing tasks in MOPP 4 (13 out 15 responding) but not in BDU (9 of 9 responding). Of 11 subjects responding, all except 1 indicated that training to perform the task in MOPP 4 would improve task performance.

While it is clear that problems were experienced in performing the various tasks in MOPP 4, Carson et al. (1989) reported that all amphibious operations observed were completed successfully during the exercise. Although there were significant problems with communications, they reported that these seemed to be amenable to training solutions. One option suggested was to use hand signals instead of verbal communications. The observers and the subjects recommended that increased training on mission-relevant tasks in MOPP 4 was needed.

f. Unopposed Armor Field Test

The U.S. Army Combat Developments Experimentation Command (1981a) conducted an unopposed field test to evaluate current tank warfare doctrine, procedures, and modeling under various CW-protective combat clothing postures. A hatch-open/ no-protective-clothing posture was used as the baseline condition to compare performance degradation (time) under various MOPP levels. Seventeen tank crews served as subjects and the test was conducted over a period of 15 days. The following six levels of CW-protective combat clothing were used:

- Baseline (hatch open, BDU)
- MOPP 1

- MOPP 3
- MOPP 4
- Buttoned (hatch closed, BDU)
- MOPP 4/Buttoned (hatch closed, MOPP 4).

Each of the 17 crews was tested over 5 different terrain "loops," each of which consisted of two similar phases. For each loop, approximately half of the crews completed both phases in the baseline posture and the remaining half completed one phase in baseline and one phase in one of five MOPP conditions. Prior to data collection, each crew wore MOPP 4 for at least 2 hours.

Analysis of the data derived from the field test consisted only of means and standard deviations. Without further analysis, no conclusions can be drawn from the study.

The U.S. Army Combat Developments Experimentation Command (1981b) conducted a field test designed to enhance current doctrine, procedures, and equipment required for reconnaissance through chemically contaminated areas. The reconnaissance team consisted of three persons; an infantry team of three persons also moved through the contaminated area. There was no analysis of the data presented in the report.

5. Development Tests

a. DT II of XM30 Protective Mask

Barnes, Hanlon, Harrah, and Merkey (1983) reported the results of the Development Test (DT II) of the XM3O Protective Mask. When compared with the M17A1, there was no difference in the mean performance time of 12 soldiers on the Mobility/Portability and Obstacle Course portion of the test. Drinking time for 250 ml of water was significantly less for the XM30 (mean of 61.7 seconds) compared to the M17A1 (mean of 79.7 seconds) but the authors concluded that the difference may not have tactical significance. Of 23 soldiers who slept while wearing the masks for one night, 7 were detected without their masks. Interviews the following day indicated that the subjects did not remember taking off the masks. In a CW-battlefield condition, these 7 soldiers would have been casualties (30 percent).

For rifle firing, performance for the no-mask condition was compared to the M17A1 and XM30. For 11 unskilled marksmen subjects, the results indicated no significant differences among the conditions.

b. XM40 Protective Masks and Rifle Firing

Merkey and Harrah (1986) investigated the effect of three XM40 prototype CW-protective masks on rifle firing performance. The prototype masks were compared to the standard M17A1 CW-protective mask and the no-mask condition. Ten subjects received training in firing at 10 silhouette targets from a foxhole position to an accuracy criterion of 14 hits out of 20 targets. The no-mask condition was used during training. During testing, the order of presentation of conditions was counter balanced and each subject (final $N = 7$) fired under 10 conditions. At the completion of the test each subject filled out a questionnaire.

An ANOVA was performed upon hit percentage and reaction time data and a Tukey's Multiple Comparison Analysis and contrasts were performed to determine which mask condition contributed to the significant effects. Significant main effects for masks and targets were found for hit percentage and reaction time. Contrasts indicated the significance was due to better performance of the no-mask conditions compared to the combined mask conditions. In addition, performance for the XM40-1 prototype condition was significantly better than the M17 conditions. The target main effect was due to better performance on targets at 75 meters compared to 100 meters and better performance on the center target compared to those left and right of center. There was also a significant mask X target interaction. We calculated the accuracy decrement (D_A) for the no-mask conditions and the three prototype mask conditions. The results indicated from −22 to −25 percent accuracy decrement for the three prototype masks. The D_A for the M17A1 condition was −27 percent. Questionnaire data indicated a slight preference for the XM40-1 prototype since the M16 did not have to be canted as much with this prototype as with the other masks. As a result of the analysis, the XM40-1 was ranked best of the three prototypes and firing accuracy performance was not significantly different than the no-mask condition. The XM40-1 was significantly better than the M17A1 for both hit and reaction time data.

The questionnaire data indicated that all subjects had to tilt their heads to obtain a sight picture. The tilt angle was less severe for the XM40-1 than the other three masks. No differences were found in terms of ranking the masks.

c. Cockpit Compatibility of the XM-43 Protective Masks

Foster, Adams, Williamson, and Nowicki (1986) summarized a field test of the cockpit compatibility of the XM-43 Protective Mask with the OH-58 and the UH-60 helicopters. The test evaluated crew performance during operational missions flown in a simulated operational environment. Five pilots were used for each helicopter to evaluate the following areas: aircraft control, communications, field binocular compatibility, night vision goggles, extended wear with the SPH-4 helmet, and Aviation Life Support Equipment. The results indicated no performance degradation for any subsystem that would cause the mission to be aborted. For the extended wear test (12-hour duty day), effective flight was defined as adequate aircraft control, not undeteriorated personnel skill.

6. Database and Model Development

a. Performance DBase System

Wick (1988) described procedures that permit performance decrements resulting from wearing CW-protective combat to be determined. A performance DBase system was developed, which provides a method to extract from a database the correction factors (the additional time required to perform a task in MOPP 4 compared to BDU) and probable range of these factors for a number of tasks and subtasks. Results from the field trials described earlier in the areas of maintenance, night reconnaissance, HAWK missile operations, armor operations, and radio teletypewriter operations were included in the database. Ten Human Ability Codes have been developed and correction factors can be extracted from the DBase system for each of the codes. Determining correction factors by scenario is obtained by a combination of task and human ability codes. Wick noted that "Attempts to extrapolate the performance data to unit operations, and in particular to large unit operations are not well-founded at this time, because of the many additional variables and complete absence of reliable data" (Wick, 1988, p. 3). He recommended that the default correction factor of 1.5, the average correction factor for all tasks currently in the DBase, be used for force structure questions.

Wick (1988) noted that frequently analysts are asked to calculate the number of additional battalions needed for operations conducted in a CW-environment. Current data in the performance DBase system are not adequate to provide this information. Field data need to be collected for unit operations operating under a standard scenario, which includes operations in a CW environment as one of the variables. He described a Force-on-Force algorithm which uses the Performance DBase System to estimate the effect of wearing CW-

protective combat clothing on battalion-size units. The algorithm provided a priority index for battalion-size units on the battlefield according to the unit's immediate contribution to the battle.

In a later report, Davis, Wick, Salvi, and Krah (1990) described the database which had been expanded to include performance decrement factors obtained from field studies for 756 military tasks. The performance decrement factor is the time required to perform a task in MOPP 4 compared to BDU. These decrements are determined by regression analysis as described previously.

Table III-17 provides a matrix of the 756 tasks distributed among 10 human ability codes and three ranges of Performance Decrement Factor ranges. Sixty-nine percent of the tasks fall into the Performance Decrement Factor range of 1.16 to 1.85, compared to 1.0 for performance in BDU. Davis et al. (1990) reported that the average Performance Decrement Factor for the 756 tasks was 1.5. The authors classified the three ranges as follows: 0-1.15 (average 1.0), not degraded; 1.15-1.85, (average 1.5), slightly degraded; and 1.85 or greater, moderately degraded. It should be noted that the range boundaries and the classification descriptions are arbitrary. Further, the Performance Decrement Factors for the 756 tasks are based on regression analysis of data from trials in which tasks were performed in BDU and MOPP 4 repeatedly. The regression analysis assumed that all learning due to repeated trials took place on the first trial. Evidence from an analysis of some of these data by Montgomery (1987) indicated that this was not a valid assumption. Thus the Performance Decrement Factors are all in error by an unknown quantity related to learning that takes place on all trials following the first trial.

Table III-17. Matrix of Percentage of Tasks for Ten Human Ability Codes and Three Ranges of Degradation (Adapted from Davis, Wick, Salvi, and Kash, 1990)

Human Ability Codes (Skills)	Number of Tasks	Performance Decrement Factor (PDF)[a] Range		
		PDF 0-1.15	PDF 1.15-1.85	PDF 1.85- Greater
		Percent		
Communication	188	2	96	2
Numerical Data	12	50	50	0
Decision Making	9	11	67	22
Precision Control	210	52	29	19
Movement and Coordination	148	10	80	10
Attention and Quickness	27	4	90	0
Visual Pattern	87	3	91	6
Manual Control	71	30	56	14
Strength and Stamina	3	0	100	0
Vision	1	0	100	0
Total % of Tasks/Range Category		21	69	10
Total Number of Tasks	756	159	522	76

[a] Performance Decrement Factor is the decrement in time when performing the task in MOPP 4 compared to BDU. Regression analysis was used to calculate the Performance Decrement Factor.

b. Human Utilization Model and Analytic Network (HUMAN)

Gawron, Lloyd, and Travole (1986) describe two models, the Human Performance Data Base and the Human Utilization Model and Analytic Network (HUMAN), that may be used to predict human performance in the CW-threat environment. The HUMAN model combines multiple data sets and provides a single prediction of human performance on complex tasks. Three categories of input data called vectors will define the CW-threat environment. Environmental, operator, and task variables are assigned to the three vectors. After the vector inputs are complete, in order to use HUMAN, the user has input skill(s) (from a menu of 10 skills) needed to perform the task. The model outputs are time to complete the task, the probability of completion, and percent errors.

Mills, Meyer, and Dunlosky (1983) reported the development of a chemical defense benchmark for human performance assessment. The objective of the benchmark was to

quantify the effects of chemical defense stressors on human performance and mission effectiveness and to determine the utility of chemical defense equipment. The following four methods of quantifying the effects of CW stressors are discussed: (1) chemical protection tests; (2) part task simulations (anthropometric/ergonomic tests); (3) full scale man-in-the-loop simulation; and (4) computer modeling. They recommend that the first three methods be used to establish a human performance assessment data base which will be used to develop and validate task, mission, and force effectiveness computer models. These models will subsequently be used as predictive tools to evaluate the need to conduct simulations on new CW equipment and to project expected test results.

C. LABORATORY STUDIES

In a review of research on the effects of heat on human performance, Kobrick and Fine (1983) concluded that the three major deficiencies of the studies were: (1) the use of artificial tasks to assess performance decrements; (2) inadequate training on the tasks; and (3) insufficient exposure to heat stress. They argue that assessment of human performance decrements due to wearing CW-protective combat clothing should be conducted with well-trained subjects using a realistic military scenario for a sustained period of at least 6 hours (Fine and Kobrick, 1987).

1. Fire Direction Center Tasks (Males)

Fine and Kobrick (1987) conducted a study to assess the effects of wearing CW-protective combat clothing on sustained performance of individual soldiers who performed aspects of tasks performed by fire direction center (FDC) forward observers and communication personnel. Twenty-three male soldiers were trained for 2 weeks on the tasks followed by 4 days of data collection for 7 hours/day. Four performance measures were used:

- Computation of "site," which is a correction for an artillery round
- Receiving and decoding grid coordinates on a map
- Receiving and decoding messages
- Plotting targets on maps and determining range and deflection.

The first three tasks were paced by the rate and frequency of radio message transmissions under the control of the experimenter. The target plotting task was under subject control. The following four experimental conditions were used on four separate days:

- BDU-Control 1 - 21.7° C, 35 percent relative humidity (rh) with the subjects dressed in BDU.
- MOPP-Control - 12.8° C; 35 percent rh, MOPP 4 worn over BDU.
- BDU-Control 2 - Repeat of condition 1.
- MOPP-Heat Stress - 32.8° C, 61 percent rh, MOPP 4 worn over BDU.

It had been determined in a previous study that conditions 1, 2, and 3 were equivalent from the standpoint of heat load. Data from 20 of the 23 subjects were analyzed. For the MOPP-Heat Stress condition, two subjects were removed from the test due to medical reasons prior to test completion, but their data were included in the analysis for the first three tasks; their scores were the maximum possible omission errors for these tasks.

The results indicated that there were no significant differences on any of the three experimenter-controlled tasks between the MOPP-Heat Stress and the two BDU-Control conditions after the first and third hours. The mean error, however, after 7 hours for MOPP-Heat Stress was significantly different (17-23 percent decrement) from the other three conditions on the three experimenter-controlled tasks (i.e., computation of site, receiving and decoding grid coordinates on a map, and receiving and decoding messages). The number of targets plotted for the sixth hour was also significantly less (40 percent) for the MOPP-Heat Stress condition than any of the three control conditions, but accuracy of plotting was not significantly affected. Almost all of the decrements were due to increased errors of omission.

2. Fire Direction Center Tasks (Females)

Fine (1987) conducted an exact replication of the Fine and Kobrick (1987) study with the exception that 18 women served as subjects. Data analysis was performed on 17 subjects.

During the MOPP-Heat stress condition, 10 subjects terminated the study for medical reasons. Two terminated during the third hour, three during the fourth hour, and five during the fifth hour. None of the subjects was terminated due to hyperthermia; only one subject's rectal temperature reached 102.2° F. There was no significant difference between the average rectal temperature of the seven subjects who completed the study (100.4° F) and those who terminated (100.8° F). The 10 subjects who terminated, however, reached the core temperature of 100.8° F considerably faster than those who completed the study, which indicates that the casualties were storing heat more rapidly than

those who completed the study. All casualties passed out, indicated that they were about to pass out, or were judged by the medical officer to be incapable of continuing the study. The seven subjects who completed the study showed no significant deleterious effects of heat stress on the performance of any task.

Due to the large number of subjects who terminated the study during the MOPP-Heat Stress condition, the decrements for the fifth and seventh hours were significantly different from all other conditions on all tasks. There was significant decrement for all hours for the MOPP-Control compared to the two BDU-Control conditions for codebook performance and for number of targets plotted; performance on the codewheel task was significantly different for hours 1 and 3.

When comparing this study with Fine and Kobrick (1987) the effect of the MOPP-Heat Stress condition was dramatically different. The 18 of the 20 male subjects performing the same tasks under identical experimental conditions completed the 7-hour exposure to the MOPP-Heat Stress condition, but only 7 of 17 women completed the 7-hour exposure.

The MOPP-Control Condition (12.8°C; 35 percent rh, MOPP 4 worn over BDU) for the Fine and Kobrick (1987) and the Fine (1987) studies used a metabolic rate for active rather than inactive soldiers to calculate thermal comfort equivalent between MOPP and BDU controls. Fine (1990) reported that this was in error and resulted in an inappropriately low ambient temperature for the MOPP-control conditions. Revised calculations used 16.3°C for males and 19.2°C for females vice 12.8°C. According to Fine, the subjects in both studies, "appear to have been exposed to mild-to-moderate cold stress" (Fine, 1990, p. 5). This is offered as a "reasonable explanation" of performance decrements during the "MOPP-Control" condition particularly for the females since they were exposed to colder temperatures than males.

3. Speech Intelligibility

Johnson and Sleeper (1985) used the Modified Rhyme Test to assess the impact of thermal stress and chemical protective combat clothing on speech intelligibility. Twenty-two male soldiers served as subjects. Six practice sessions were conducted to familiarize the subjects with the 300-word test set. The Modified Rhyme Test consisted of administering a subset of 50 words at 5-sec intervals. The dependent measure was the percent of words correctly identified.

An audiometric test with and without the M17A1 mask indicated significantly increased thresholds for the mask condition for the following frequencies: 500 Hz, 4000 Hz, and 6000 Hz.

The subjects were administered the Modified Rhyme Test three times during a 7-hour test day (at hours 2, 4, and 6) on four consecutive experimental days. The ambient temperature and clothing conditions as well as the subjects were the same as those in Fine and Kobrick (1985):

- BDU-Control 1 - 21.7° C, 35 percent rh
- MOPP 4-Control - 12.8° C, 35 percent rh
- BDU-Control 2 - 21.7° C, 35 percent rh
- MOPP 4-Heat Stress - 32.8° C, 61 percent rh.

A two-by-three (conditions by hours) analysis of variance indicated significant main effects for conditions and hours. In addition, there were significant interactions. Twenty multiple comparisons indicated the conditions main effect was due to heat stress (about a 14 percent decrement); the hour main effect was due to decrements during hour 6. The MOPP 4-Heat Stress for hour 6 was significantly different from all other comparisons.

4. Effects of CW Masks on SPH-4 Aviator Helmet

Mozo and Peters (1984) investigated the effects of chemical protective masks on the hearing, protective, and communication aspects of the SPH-4 aviator helmet. Three CW masks (M-24, XM-33 and the UK AR-5) and two oxygen masks (P/Q and MBU-13) were evaluated to determine their effects on speaker intelligibility, listener intelligibility, and attenuation. Ten subjects were presented phonetically balanced words to determine intelligibility. The test condition simulated a UH-60A noise environment. The results indicated that the XM-33 is very deficient in terms of speech intelligibility. The M-24, AR-5, and P/Q improved the intelligibility of the SPH-4 helmet. All CW masks degrade speech intelligibility when used by a listener wearing SPH-4. The M-24 and XM-33 masks, with and without the protective hood, degrade the attenuation characteristics of the SPH-4 helmet.

5. Effects of XM-40 Masks on Attenuation and Speech Intelligibility of SPH-4 Helmet

In an additional test, also using 10 subjects and similar methodology, Nelson and Mozo (1985) investigated the effects of the XM-40 CW mask on attenuation and speech intelligibility of the SPH-4 aviator helmet. There was little difference in the attenuation of the SPH-4 with and without the mask at all frequencies except 2000 Hz, 6300 Hz, and 8000 Hz, significant differences in attenuation were found for these frequencies. Nelson and Mozo (1985) indicated that the results indicate that high frequency attenuation is compromised significantly when the XM-40 mask is used with the SPH-4 helmet. They found that the XM-40 CW mask significantly reduces speech intelligibility for a listener. Tests using three XM-40 CW masks, which differed with respect to the configuration of the microphone within the mask, indicated that each significantly reduced speech intelligibility of the SPH-4.

6. Visual Perception

Kobrick and Sleeper (1986) investigated the effect of wearing CW-protective combat clothing on visual perception. Sixteen male subjects were exposed to two environmental conditions, i.e., 91°F/61 percent rh and 55°F/35 percent rh while wearing MOPP 4. A control wearing the BDU and exposed to 70°F/35 percent rh was also used. Visual stimuli were presented along three axes from central visual to the peripheral limit of the visual field (90°). Following 2 weeks of training, the subjects were exposed to three experimental conditions over 4 days. The first day was 55°F/35 percent rh (MOPP 4); the second day was control (70°F/35 percent rh) in BDU; the third day was 91°F/61 percent rh (MOPP 4 plus heat stress) and the fourth day was a repeat of control (day 2). The results indicated that mean response times increased for all three experimental conditions as the stimulus presentation was systematically moved from central to peripheral vision. The means for MOPP 4 and MOPP 4 plus heat stress were greater for all stimulus locations when compared to the means for the two control conditions, but no statistical test was conducted. The overall group means for the two experimental conditions were greater than the two control conditions but no statistical test was conducted. The overall mean and the individual stimulus location means for the second control day were less than the first control day, indicating a performance improvement. These differences were not tested statistically. The results indicated a serious limitation to vision by MOPP 4.

7. Manual Dexterity

Johnson and Sleeper (1986) reported the results of the use of two standard psychomotor tests, the O'Connor Fine Finger Dexterity Test and the Purdue Pegboard Assembly Test, to determine the effects of chemical protective clothing (butyl rubber gloves and gas mask and hood) on manual dexterity. Twenty-two male soldiers served as subjects. The tests were conducted over a period of 5 days under the following four conditions:

(1) control - bare-handed and bare-headed
(2) bare-handed and wearing gas mask with hood
(3) bare-headed and wearing gloves
(4) wearing gas mask with hood and gloves.

A three-way analysis of variance was used to analyze the performance results (time to complete) on each test. For each analysis, gloves produced a significant decrement in manual dexterity but wearing the mask with hood had no effect on dexterity. There was also a significant "days" main effect and a significant days X glove interaction. Twenty multiple comparison tests indicated that the subjects reached performance asymptote on the O'Connor test at day 4 when wearing gloves and day 3 when bare-handed, and on the Purdue Pegboard Test at day 3 when gloved and test day 1 when bare-handed. The authors concluded that it takes longer to become proficient at manual dexterity tasks when wearing gloves than when bare-handed. On the fifth day dexterity while wearing gloves was significantly different from the bare-handed conditions. At asymptote for both conditions, it took subjects three times as long to perform the Purdue Pegboard Test when wearing gloves compared to the bare-handed condition.

Johnson and Sleeper (1986) recommended that soldiers be given intensive training in job-specific tasks while wearing CW-protective combat clothing, especially if the task requires an appreciable amount of manual dexterity. We calculated from their data that practice over 5 days results in an improvement of approximately 33 percent on both the O'Connor Finger Dexterity Test and the Purdue Pegboard Test when gloved.

8. Tactility of CW Gloves When Performing Medical Tasks

King and Frelin (1984) compared the ability of medical specialists to perform nine basic medical tasks while wearing the BDU or MOPP 4 with the standard butyl rubber glove and MOPP 4 with a prototype glove designed to increase tactility sensitivity. In each

clothing condition, nine subjects performed the nine basic medical tasks, which were selected to emphasize dexterity and coordination for 6 consecutive days. The nine medical tasks were to: (1) administer emergency care to a CW casualty, (2) immobilize a fracture, (3) apply a splint to a lower extremity, (4) initiate a field medical card, (5) apply a dressing, (6) apply a tourniquet, (7) administer morphine by syrette, (8) administer first aid for a sucking chest wound, and (9) initiate an intravenous infusion. Time to accomplish the tasks and errors were recorded. On day 1, testing occurred first in fatigues. The order of each day's activities was determined randomly, subject to the constraint that each of the six test sequences occur once.

For day 1, the mean time to complete each of the nine tasks was longer for the fatigue condition (first test condition) than for MOPP with the prototype glove or for MOPP 4. For the first day the time to complete each of the day's tasks was longer in MOPP 4 than MOPP with the prototype glove.

Generally the mean performance time decreased during the 6-day test for all three conditions. The largest improvement for each of the nine tasks was between day 1 and 2 for the fatigue condition. Also for all tasks, performance in MOPP 4 improved over the 6 days. On the last day (day 6) all tasks were performed significantly more slowly in MOPP 4 than in fatigues. For day 6, performance was also slower for MOPP 4 compared to MOPP with the prototype glove for seven of the nine tasks; performance for MOPP with the prototype glove was slower for seven of nine tasks as compared to performance with fatigues. Errors were not significantly different across the three clothing conditions.

When checked for flaws after day 3, 10 of 18 of the prototype gloves had flaws and after day 6, 15 of 18 gloves had flaws; none of the standard butyl rubber gloves developed flaws.

It is important to note that all subjects were able to accomplish all tasks on all days while dressed in MOPP 4 and the MOPP 4 with the prototype glove conditions. Performing these tasks took longer due to the use of CW-protective gloves. The authors emphasize that practice in CW-protective combat clothing is important since performance using MOPP 4 improved for all tasks. Practice did not, however, eliminate the performance decrement. For day 6, the percent decrement (D_T) for MOPP 4/Fatigues for the nine tasks ranged between −27 and −94 percent and the mean percent decrement (D_T) was −53 percent. The authors concluded that basic medical tasks can be accomplished in MOPP 4 if troops are trained to perform in the protective ensemble.

9. Psychological Effects

Hamilton and Zapata (1983) investigated the psychological effects of wearing CW-protective combat clothing. Twenty-four subjects, 12 males and 12 females, were used for the test; 12 subjects wore flight suits and 12 wore CW ensembles. All subjects were administered, before and after wearing the CW ensemble for 6 hours, a mood scale and the following four cognitive subtests of the Walter Reed Performance Assessment Battery (PAB): Serial Math, Target Detection, Logical Reasoning, and Reaction Time.

Percent of change scores as described by Hamilton, Simmons, and Kimball (1982) were used as the dependent measure. Some subjects had large percent of change scores, which was assumed to be a learning effect. Percent of change scores above 50 percent were eliminated from the analysis. For each subtest the measures were the number attempted, number correct, reaction time correct, and reaction time error. Two-factor ANOVAs (ensemble and sex) were computed for Serial Math, Target Detection, Logical Reasoning, and Reaction Time. The ANOVA for Serial Math resulted in a significant difference for reaction time correct; the female CW ensemble was significantly less than the other three conditions. The ANOVA for Target Detection resulted in significant differences for sex and a sex by ensemble interaction. For the Logical Reasoning ANOVA, the only significant measure was reaction time correct for ensemble (CW ensemble deficit for both male and female). No significant differences were found for Reaction Time for any of the four conditions.

There was a lack of statistical reliability of the variables tested. There were few measures of performance across either sex or ensemble that were significantly different, and there were large standard deviations for all subtests. The ambient Wet Bulb Globe Temperature (WBGT) for males and females differed. Only females experienced temperatures in excess of 24°C. There was significant evidence that the subjects were bored by the experimental conditions, (i.e., the 6-hour period during which the subjects wore the CW ensemble or flight suit) since there was no organized activity during this time. Due to the lack of statistical reliability, it was impossible to draw conclusions from the test.

10. Cognitive Problem Solving

Rauch, Witt, Banderet, Tauson, and Golden (1986) conducted a study to determine the effects of wearing chemical combat protective clothing on cognitive problem solving over a 24-hour period of continuous operations. Nine subjects were given three paper and pencil tests of cognitive performance at seven scheduled times throughout each 24-hour

period of testing. The three tests were: (1) Math Computation, i.e., the addition of three 2-digit numbers arranged vertically; (2) Pattern Recognition, i.e., recognition of the correct list among eight alternatives; and (3) Number Comparison, i.e., comparing two horizontally arranged 3- to 9-digit numbers. Six subjects were randomly assigned to each of three crews. Each crew performed artillery Fire Support Team (FIST) operations for three 24-hour periods under the following three clothing conditions: (1) BDU, (2) MOPP 2, and (3) MOPP 4 (order was randomized).

The experimental design was a 3-×-7 repeated measures analysis of variance on two dependent variables, i.e., percent of problems completed and percent of problems wrong. Significant main effects of MOPP and of time of day were found for all three cognitive tests for percent completed. A Scheffe test indicated that MOPP 4 performance was significantly degraded for each of the three cognitive tests when performance in BDU was contrasted with MOPP 4. From the raw data presented in Table 1 of the Rauch et al. (1986) report, we calculated the following time degradation (D_T) comparing MOPP 4 to BDU:

- Percent Computation Attempted/Min, −13 percent
- Percent Pattern Recognition Attempted/Min, −15 percent
- Percent Number Comparison Attempted/Min, −17 percent

The contrast between BDU and MOPP 2 was not significant.

We also computed the following percent accuracy degradation (D_A) comparing MOPP 4 to BDU:

- Percent Computation Error/Min, −14 percent
- Percent Pattern Recognition Error/Min, −22 percent
- Percent Number Comparison Error/Min, −59 percent.

Thus we found both accuracy and time degradation when MOPP 4 was compared with BDU.

In a later study, Rauch and Tharion (1987) reported the effects of wearing the chemical protective mask and gloves on cognitive problem solving. The study investigated the effect of the following four conditions: (1) wearing CW-protective gloves; (2) wearing the CW-protective mask; (3) wearing both the mask and gloves; and (4) wearing no gloves and no mask. Eight female and seven male volunteers served as subjects. The cognitive test consisted of a paper and pencil test of math computation (adding three 2-digit numbers arranged vertically). The experimental design consisted of a two-factor between-subjects

(SEX) and a four factor within-subjects (conditions) repeated measures analysis of variance (order of conditions was randomized for each subject). Alternate test forms were used for each condition and each subject was given 12 practice problems prior to each test which was 2 minutes in duration. The dependent measures were the number of problems completed in 2 minutes and the number of problems wrong.

A significant main effect was found for the number of problems completed. No other significant differences were found. A least-significant difference test was performed which indicated a significant contrast between wearing both the CW-glove and mask and the no glove/no mask conditions ($D_T = -10\%$) and between wearing the CW-glove and the no glove/no mask conditions ($D_T = -8\%$). The authors concluded that differences were due to limitations on manual dexterity and on sensory-perceptual capabilities.

11. Training Procedure For Donning Masks

Driskell, Carson, and Moskal (1986) examined the effectiveness of the chemical simulation training procedure for Navy recruits. As a part of the training, the recruits don gas masks, enter a chamber contaminated with CS, a riot control gas, and remove the mask before leaving the chamber. The subjects were 362 male and female recruits. A 20-item questionnaire designed to determine the following five factors was administered:

(1) Perceived skill or ability to perform task
(2) Anticipate mastery in a specific situation
(3) Willingness to perform in the environment
(4) Confidence in equipment
(5) Subject matter knowledge as a result of classroom training.

The trainees were divided into three groups (three conditions):

(1) Questionnaire prior to any chemical warfare training
(2) Questionnaire after classroom training but prior to chamber training
(3) Questionnaire at the completion of training.

To determine the differences between the three conditions, t-tests were run and resulted in the following findings:

- Trainee knowledge scores increased as a result of classroom instruction and remained stable following the chamber exercise ($p < .001$).

- There was a significant decline in performance expectations as a result of the chamber exercise ($p < .001$). The subjects who formed high performance expectations reported significantly less stress during the chamber exercise than those of low expectations. Inability to wear glasses (for those who normally wear them) and a poor mask seal both produced poor performance expectations and induced greater stress.

12. Performance Effects of Drug Antidote and Heat Stress

Kobrick, Johnson, and McMenemy (1988; 1990a; 1990b) investigated the effects of nerve agent antidote and heat stress on performance while wearing chemical combat protective clothing. Two studies, one in BDU and one in MOPP 4, were conducted. For the BDU study, 15 male soldiers served as subjects and for the MOPP 4 study, eight male soldiers served as subjects. Each group was trained for 6 hours/day for 5 days on the following tasks: visual accuity, phoria, stereopsis, contrast sensitivity, speech intelligibility, arm-hand steadiness, muscle tremor, gross dexterity, one-hand and two-hand fine dexterity, body mobility, simple and choice visual reaction time, simulated rifle marksmanship, verbal reasoning, digit-symbol substitution, eye-hand coordination, and tapping. Following training, each group of subjects were tested on the above tasks in three, 2-hour tests (total of a 6-hour period) for 4 test days. For BDU, the following conditions were used: (1) control (saline; 70°F, 30%rh); (2) drug (2 mg atropine, 600 mg 2-PAM; 70°F, 30%rh); (3) ambient heat stress (saline; 95°F, 60%rh); (4) drug and ambient heat stress (2 mg atropine, 600 mg 2-PAM; 95°F, 60%rh). For MOPP 4, the conditions remained the same (trained and tested in MOPP 4) except for the control and drug the condition was 55°F, 30%rh to offset the heat load due to wearing MOPP 4. In addition to the above tests, the Environmental Symptoms Questionnaire (ESQ) and the Profile of Mood States (POMS) were administered at the end of each test day and the Brief Subjective Rating Scale (BSRS) was given at the end of each 2-hour test period. Separate three-way analyses of variance with repeated measures were conducted for BDU and for MOPP 4 for each performance task.

For the BDU subjects significant drug main effects were found for a number of the performance and visual variables but only the significant heat stress main effects will be discussed. The significant main effects for heat stress were altered steadiness and rifle marksmanship. ANOVAS for the POMS and BSRS showed that the subjects were significantly hotter and more uncomfortable and tense at 95°F, 30%rh. For the ESQ under

the heat stress condition, the subjects were "warm, sweating," and for the drug and heat stress condition," headache and light headedness" were reported.

For the MOPP 4 subjects, the heat stress was so severe that only one of eight subjects completed the second 2-hour testing cycle, and no subjects started cycle 3. For the heat stress and for the heat stress and drug conditions, four subjects were removed by the medical monitor and four withdrew. A t-test of the mean exposure time was conducted. The findings indicated a significant difference between the mean exposure times of heat stress (183.63 min) and the heat stress and drugs (149.25 min). Thus a single dose of atropine and 2-PAM effectively reduced the endurance time of soldiers in MOPP 4.

The worst scores possible for the test condition were assigned where subjects withdrew or were removed by the medical monitor and three-way analysis of variance (drug × temperature × cycle) with repeated measures was computed. Significant effects were found for all performance tasks for the heat stress condition. For POMS, significant main effects for heat stress were found for tension, depression, fatigue, and confusion. For BSRS, significant heat stress main effects were found for tiredness, discomfort, and warmth. For the ESQ, the authors also reported the MOPP 4 resulted in "far more numerous symptoms being reported than for the same testing conditions under BDU." These included bodily discomfort symptoms and mood effects.

While wearing MOPP 4 under the heat stress condition resulted in a disruption of performance, it should be emphasized that subjects were able to remain operational under the control condition (55° F, 30 percent rh) while wearing MOPP 4. The authors also note that there was no evidence of claustraphobia and/or anxiety reaction due to encapsulation.

13. Rifle Marksmanship

Johnson, McMenemy, and Dauphinee (1990) and Johnson (1991) evaluated the effects of rifle marksmanship under the following three combat clothing conditions: BDU, the fighting load (BDU plus helmet, web gear and full canteen), and MOPP 4. An M-16 simulator, the Weaponeer Marksmanship Trainer, was used to collect performance data. The subjects were 30 male soldier volunteers; 10 subjects, matched on marksmanship ability, were assigned to each group. Following 4 days of practice on the simulator, the subjects' marksmanship on pop-up targets was assessed in rifle supported and unsupported conditions. A 3 × 2 (clothing × rifle support) ANOVA was used to evaluate the pop-up target data (total number of targets hit) and a Kruskal-Wallis one-way (clothing) analysis of variance by ranks was used to analyze the number of attempts before a tight shot group was

obtained. The results indicated a significant main effect for clothing and for rifle support. Newman-Keuls tests indicated that rifle marksmanship was significantly poorer under MOPP 4 (mean of 22.1 hits) when compared to the BDU (27.4 hits) or the fighting load (26.0 hits). D_A scores comparing MOPP 4 and BDU and MOPP 4 and fighting load clothing conditions were −19.3 percent and −14.9 percent, respectively.

14. Pilot Performance

Thornton and Caldwell (1991) conducted a study in the UH-60 simulator to determine the effect of CW-protective combat clothing on pilot performance. Sixteen male Army aviators who were qualified in the UH-60 helicopter served as subjects. Two pilots (one left seat and one right seat) were involved in each flight. Pilot performance for two clothing conditions, flight suit and MOPP 4 (Aircrew Uniform Integrated Battlefield) and M43 mask, was investigated. The simulated tactical flight profile consisted of a 1-hour tactical low level navigation exercise followed by an hour of upper air maneuvers. The automatic flight control system was disabled during the latter half of the upper air phase to increase the workload. In order to obtain performance data for the two pilots, each controlled the helicopter simulator at predetermined intervals during the flight.

The flight profile was divided into nine separate maneuver types and each maneuver was scored for several different parameters which varied with the maneuver. There were 69 separate flight maneuvers per test day with up to 5 parameters each. RMS error was computed from data recorded on a 16-channel flight data recorder.

A week of training on the flight profile was conducted and was followed by a test week. The environmental conditions consisted of mild and hot conditions measured as dry bulb temperatures as follows: T_1 (mild) = 21.6°C, rh 50% and T_2 (hot) = 35.9°C, rh 50%. The experimental design during the testing week was as follows:

Monday baseline, flight suit, T_1

Tuesday flight suit, T_2

Wednesday MOPP 4, T_1

Thursday MOPP 4, T_2

Friday flight suit, T_1

An analysis of variance was performed on the RMS error values and Duncan's multiple range test was used for posteriori comparisons.

Pilot performance showed a marked improvement between the first and second training sessions but was stable following the second session. For the test week, comparisons were made across the four conditions: (1) baseline; (2) flight suit, hot; (3) MOPP 4, mild; (4) MOPP 4, hot. There were 19 maneuver parameter comparisons for which the MOPP 4 hot performance value (RMS error) was significantly greater than at least one of the other groups. For MOPP 4, mild and flight suit hot, four comparisons were greater and for baseline, two comparisons were greater. The authors interpret the lack of consistency across the data to indicate that the degree of performance decrement was minor. When the automatic flight control system was disabled, the RMS error was greater for most maneuver parameters when compared to the maneuver parameters with the system's normal operation.

15. Pursuit Tracking

Barba, Stamper, Penetar, and Molchany (1987) investigated the effects of wearing the M17A2 protective mask on pursuit tracking performance. They found that wearing the protective mask significantly reduced the ability to detect, acquire, and track moving targets. Tracking data were collected under two ambient light conditions; the dim condition approximated dawn/dusk. All subjects were trained for 2 days without the protective mask. For 3 test days 20 trials a day, divided equally between the two light conditions, were conducted for a control group (no mask) and an experimental group (protective mask). A between-subjects design was used and vertical and horizontal data were used to compute the following scores: Percent Time-on-Target Root Mean Square Error (RMS) and Maximum Absolute Error. Percent time-on-target decreased significantly when the protective mask was worn under both the bright light (8 percent) and the dim light (21 percent) conditions.

From the raw data presented by Barba et al. (1987), we calculated percent accuracy decrement (D_A) for RMS and found the vertical and horizontal components to be −39 percent and −29 percent, respectively, for the dim light condition. The D_A for the maximum absolute error for the vertical and horizontal components for the dim light condition was −68 percent and −35 percent, respectively. The authors concluded that soldiers using direct-view optics such as TOW and GLLD could experience severe difficulties when wearing the protective mask due to the decreased field of view and inability to visually scan the scene (horizontal component). They also concluded that "training with the M17A2 protective mask would provide tracking strategies. . . . [W]ithout

this training the success of the mission could be compromised" (Barba, et al., 1987, pp. 15-16).

16. Tactical Computer Terminal Operations

Lussier and Fallesen (1987) evaluated the capability of a Tactical Computer Terminal (TCT) operator to accomplish 11 tasks while wearing MOPP 4. Performance of the tasks (time and errors) was measured while the subjects were dressed in BDU and in MOPP 4. Half of the 12 subjects performed the task first in BDU and half in MOPP 4; for the second trial the clothing conditions were reversed. None of the subjects had prior training in operating the TCT while wearing MOPP 4, but all had attended a 2-week new equipment training course 7 months prior to the test. The results indicated that the subjects were able to perform the 11 tasks under the two clothing conditions. The overall degradation for the MOPP 4 condition for the 11 tasks was –8 percent (+12 percent to –36 percent).

17. Scanning Time with XM40 Mask

Harrah (1984a) conducted a study to determine the performance decrement due to wearing CW-protective combat masks. The time required to scan an area using the M17 mask and three versions of the XM40 mask was compared to scanning without a mask. The field of view with M19 binoculars in the no-mask condition was 6.6° compared to 2.8° to 3.1° field of view wearing masks. Mean scan time for the no-mask condition was 8.6 sec compared to between 44.6 and 48.4 sec for the mask conditions. All masks that were tested significantly degraded visual scan time. There were no significant differences among masks for scan time.

In a later report, Harrah (1985) found that, compared to a no-mask condition (mean scan in sec = 26.34), the time required to scan a target was significantly degraded for the M17A1 protective mask (43.94 sec.) and for three versions of the XM40 prototype protective masks (range 44.57 to 50.23 sec.). No difference in time to scan a target was found between the standard and the prototype masks. The percent time performance degradation (D_T) (calculated from Harrah, 1985 data) ranged between –67 percent for the M17A1 and –91 percent for one of the XM40 prototype masks.

18. Missile Maintenance Performance

Waugh and Kilduff (1984) conducted a laboratory study to determine if the performance of missile maintenance personnel wearing CW-protective combat clothing would experience degradation in the performance of representative maintenance tasks. Eleven enlisted males and one female served as subjects (two of these were alternates). Two tasks were chosen, an easy task and a difficult task. The easy task was performance of the TOW self-test routine. The difficult task was to remove and replace a motor-driven rotating mirror assembly deep in the tracker portion of the Dragon night sight. The following experimental conditions were used: (1) BDU; (2) BDU with protective mask and hood; (3) BDU with protective gloves with cotton liners; (4) MOPP 4. The two repair tasks were performed by each subject under each experimental condition. The experiment was replicated two times. The order of experimental conditions was randomized. A two-way ANOVA (conditions X subjects) design was used to test for differences among the experimental conditions with the three replications combined. A two-way ANOVA (conditions X replications) design was used to test for differences for each replication. Separate analyses were performed on the easy and the difficult tasks. Time to complete the tasks was the dependent variable. One subject withdrew from the test late in the trials. The data set was based on nine subjects.

The results indicated no differences in the mean times among conditions for the easy task, but there was a decrease in mean times by replications. For the difficult task, the mean time was lowest for BDU and highest for MOPP 4 for all replications. Improvement in mean times was found for each replication for each condition with the exception of BDU replications 2 and 3.

A two-way ANOVA (conditions X replications) for the easy task was significant for replication but not condition. The ANOVA for the difficult task indicated a significant difference for conditions and for replications.

Duncan Multiple Range tests indicated that the first replication for the easy task was significantly different from replications 2 and 3. For the difficult task, these tests indicated a significant contrast between the first replication and replications 2 and 3; a significant contrast between BDU and MOPP 4; and with condition 2 BDU and mask/hood and condition (BDU and glove) no mask/hood and gloves; and for MOPP 4 and mask/hood and gloves.

For the difficult task, learning was found for BDU and MOPP 4. Performance was degraded an average of 18 percent for mask/hood and for gloves when compared to BDU.

19. Effects of CW Gloves on Digital Terminal Performance

Peterson (1986) reported on a test of the TA-954, a non-secure digital terminal used in TRI-TAC communication systems, to determine if a soldier's ability to use the terminal is degraded when wearing MOPP gloves/cold weather gloves. Three types of CW-protective gloves and the arctic mitten were worn by 31 soldiers. The CW-protective gloves were 7-mil (0.007 inch), 14-mil, and the standard 22-mil butyl rubber. The subjects were told that accuracy was more important than speed. The results in terms of character accuracy rate and message error rate indicated no significant difference in character accuracy rate or the message error rate between the no-glove baseline condition and any of the CW-protective gloves. There were, however, significant differences between the baseline and CW-protective gloves when worn with cold weather gloves.

20. Survey of CW Common Defense Skills

Moskal, Driskell, and Carson (1987) conducted a study to assess the common skills required for chemical, biological, and radiological warfare defense. A 37-item knowledge questionnaire was administered to 333 naval personnel on 16 ships. Almost 50 percent of those surveyed had not been involved in any shipboard chemical defense exercise; two-thirds of the remainder reported that they had participated in one to three exercises. Two-thirds reported that they had worn CW-protective combat clothing (on any occasion) for a maximum of zero to 60 min. Forty percent reported that the last chemical defense training occurred in recruit training, generally 1 year prior to taking the questionnaire.

The mean score for correct answers was 12.6 (34 percent) and the range of correct responses was from 9 to 60 percent. Only 7.5 percent of the personnel tested were able to answer the 11 items on the questionnaire considered critical to survival in the event of chemical attack. One hundred eighty-two of the subjects (54.7 percent) failed to answer even one of the 11 critical items correctly.

The large sample of subjects was found to have had very little prior practice performing the common chemical defense skills. The number of shipboard exercises completed, the length of time that CW-protective combat clothing had been worn and the recency of chemical defense training were all positively related to high scores on the

questionnaire. Knowledge of donning and doffing procedures for CW-protective combat clothing was the poorest of all 11 categories. The authors concluded that further training in the common skills area was crucial.

IV. DISCUSSION

It is well known that wearing CW-protective combat clothing may protect the wearer but it also results in impairment of human performance. Many studies including combined arms exercises, field trials, and laboratory studies reviewed in this paper and in previous papers (Taylor and Orlansky, 1986, 1987) have documented the degradation of both individual and unit performance. Banderet (1991a) has suggested that the various performances should be differentiated rather than using "performance" as a generic construct. Most of the studies reviewed, however, failed to differentiate performance.

Heat stress, due to wearing CW-protective combat clothing, seriously degrades performance (under some conditions within an hour); this finding is supported by many studies reviewed in this paper and in previous papers by Taylor and Orlansky (1986, 1987). Heat stress effects have been accurately modelled using laboratory data collected on males.

Two laboratory studies, which used identical experimental procedures to assess the effects of wearing CW-protective combat clothing on performance of fire direction center tasks, found that performance under the "heat stress" condition produced performance decrements. In one study, 18 of 20 male subjects completed the 7-hour test but showed performance decrements. In a second study involving females, 7 of 17 female subjects completed the 7-hour test while 10 of 17 females terminated the study for medical reasons; none of the terminations was due to normal indications of heat stress. It is important to note, however, that casualties appeared to be suffering classic symptoms of heat stress, e.g., syncope (Cadarette, 1991). All casualties passed out, indicated that they were about to pass out, or were judged to be incapable of continuing by medical personnel. The seven survivors showed no significant performance deterioration. These results suggest that females perform better than males up to the point of being unable to continue the test, but fewer were able to complete the test as compared to males.

The above laboratory studies, which compared male/female performance differences on fire direction center tasks, suggest differences in physiological tolerance to heat stress, with female tolerance being lower. We constructed Table IV-1, a two-by-two

contingency table, to test the hypothesis of no differences between males and females in completing the test.

Table IV-1. Contingency Table of Males and Females Who Completed Test

Completed Test	Males	Females	Total
Yes	18	7	25
No	2	10	12
Total	20	17	37

The exact X^2 probability for the arrangement in contingency table was computed assuming fixed marginal frequencies and using the formula (Walker and Lev, 1953):

$$\frac{(a+b)!(c+d)!(a+c)!(b+d)!}{N!a!b!c!d!}$$

The exact X^2 probability was $P = < .002$ thus indicating a significant difference between males and females in completing the test.

Nunneley (1978) has reviewed the physiological responses of women to heat stress. The review indicated that females (drawn from the general population) are less heat tolerant than their male counterparts. Differences in body size, with a lower body weight and surface area but a higher surface-area-to-mass ratio for women was discussed. Cadarette (1991) pointed out that the generally smaller stature of females compared to males would result in the weight of the CW-protective combat clothing imposing a more severe strain on females as compared to males. He also indicated that females would have a smaller plasma volume and consequently could be expected to have a greater incidence of syncope when wearing MOPP 4 as a result of "blood pooling in the periphery from vasodilation in an attempt to increase heat loss from the core" (Cadarette, 1991). Nunneley (1978) also reported that end points of heat stress, such as maximum core temperature and heart rate, are the same for males and females. She found that the following factors contributed to the limited heat stress tolerance in women: (1) small size; (2) high fat content; (3) low work capacity; and (4) lack of acclimatization. She reported that all factors show large individual variation and that male-female differences in response to heat stress are not found when women are physically trained and/or heat acclimatized.

Data from Shapiro, Pandoff, Avellini, Pimental, and Goldman (1981) suggested that men and women have qualitatively similar heat balance and heat transfer characteristics.

They reported that the female's higher surface-area-to-mass ratio is an advantage for hot-wet environments, but in hot-dry environments women have an increased skin temperature.

In 1981, Rakaczky noted that no field tests had been reported in which females were involved. This report reviews one field test conducted in a tropical environment whose purpose was to evaluate male/female differences. Some evidence was presented that indicated differences between male and female tolerance to heat stress as measured by core temperature (females were lower) but the limited number of subjects in each group (an N of 5) prevented statistical analysis. The experimental data comparing male and female differences in performance to heat stress while wearing CW-protective combat clothing is extremely limited. In view of the increased numbers of females involved in combat support roles and the potential of females being involved in combat situations in which a substantial CW threat exists, this area warrants increased research emphasis.

Many of the studies conducted under the P^2 NBC^2 program indicated inability of volunteer subjects to complete a variety of sustained combat missions in moderate or hot environments. In most cases the subjects elected to leave the study prior to being medically removed due to elevated core temperature or high heart rate. Studies indicated that the combat unit was judged to be "combat ineffective" due to the loss of personnel prior to completing the continuous operation scenario. In some cases the continuous operation scenario could not be completed in BDU. In all cases in which BDU and MOPP 4 were compared, the MOPP 4 condition produced more "casualties" and caused the combat unit to become combat ineffective in a shorter time when compared to BDU.

These studies investigated continuous operations in MOPP 4 in the following areas: armor, mechanized infantry, artillery, and aviation. Ellis et al. (1986) reported that tank crews in a tank turret trainer had difficulty completing a 24 hour period of continuous operations in MOPP 4 even with a work/rest cycle of 2 hours of work in MOPP 4 and 1 hour of rest in BDU. When an ammunition loading exercise was added to the scenario and the rest cycle eliminated, no crew lasted longer than 9 hours of a 24-hour extended operations period. Ellis et al. (1986) found that no armor crew completed continuous combat operations in a stationary tank (M60A3 or M1) for more than 11 hours of a 24-hour scenario. The average crew member's endurance was 8.73 (M60A3) and 5.25 hours (M1), respectively. In a subsequent 24-hour test involving a realistic tactical scenario against an opposing force, Ellis et al. (1986) found that the average crew endurance time for the M60A3 was 7.83 hours. "The average crew endurance time for the M1 was 7.81 hours, while the average crew endurance time for the M1A1 with microclimate cooling was

16.94 hours." Clearly the microclimate cooling system of the M1A1 extended the endurance time of the crews. The authors reported that the "volunteer agreement gave the test directorate very little leverage in persuading test subjects to push themselves to their limit" (Ellis et al., 1986, p. 1-8). Glumm (1988) also found that the range of endurance for tank crews wearing MOPP 4 (36 crew members) was between 9.8 and 23.5 hours out of a 72-hour simulated tactical scenario for the M1 tank. The mean staytime was 13.6 hours. For four crews in BDU (16 crew members) the range of endurance times was 16.5-32.3 hours. The mean staytime was 22.4 hours. The staytime for individual crew members for both MOPP 4 and BDU was between 3 and 32 hours. The mean withdrawal time was 14.5 hours. None of 12 tank crews involved in the field trial completed the 72-hour field trial. The staytime ranged between 3 and 32 hours and the mean crew staytime was 14.5 hours. A rectal temperature of 39.2°C (102.5°F), which equates to a 25 percent risk of heat exhaustion if corrective measures are not taken, has been used in most laboratory and field trials as the temperature at which to medically remove a subject from the study. Indeed, Redmond, Leu, Papp, Hall, Galinsky, and Gutierrez (1991) reported that "subjective symptoms of stress often occur well before objective signs of injury. These symptoms are quite enough to limit the subject's capacity to continue and may impede his/her ability to perform tasks safely." Core temperature measurements indicated that heat stress was not a factor. Knox et al. (1987) conducted a field trial in which 12 armor crews (with four crewmen each) in BDU, MOPP 4, and MOPP 4 with microclimate cooling and coping strategies and materiel fixes to CW-protective combat equipment defended a ridge line against an opposing force during 48 hours of continuous operations. None of the crews completed the 48 hours of operations. One crew wearing MOPP 4 with microclimate cooling and using coping strategies and materiel fixes completed 16.41 hours and one crew wearing BDU completed 15.01 hours without microclimate cooling. The average staytime for crews without microclimate cooling was about 6 hours. Performance measures were not reported.

Headley et al. (1988) and Rauch, Banderet, Tharion, Munro, Lussier and Shukitt (1986) found that none of the three, 9-man howitzer crews wearing MOPP 4 was able to complete a 72-hour fire mission (250 rounds). The first casualty occurred after 1.3 hours and the three crews were combat ineffective after 3.8, 1.9, and 2.1 hours, respectively. A crew dressed in BDU completed the 72-hour scenario.

Mitchell, Knox, and Wehrly (1987) reported that none of the mechanized infantry crews wearing MOPP 4 while operating BIFV and M113A1 vehicles in a 72-combat

scenario (3.9-mile track with combat related tasks) was able to complete the test, which was terminated after 32 hours. The average staytime of crew members was 18.9 hours. There were 11 casualties out of 26 test subjects.

Mitchell et al. (1986) reported that 6 aviators operating for 6 consecutive days (MOPP 4 for 12 hours and MOPP 1 for 12 hours) terminated 12 of 20 missions when flying without microclimate cooling. Hamilton et al. (1982) reported that only 1 of 4 subjects dressed in MOPP 4 was able to complete six missions (2/day for 3 days with a day of rest between the flight days); two subjects in MOPP 4 were removed due to elevated core temperature.

The data related to staytime in tests of combat arms raise serious questions concerning sustained combat unit performance while wearing CW-protective combat clothing even when heat exhaustion is not a factor. It is difficult to determine precise physiological end points from the above data, but what has been determined is that crews dressed in MOPP 4 in temperate climate conditions will have difficulty sustaining effective combat operations under CW conditions for extended periods of time.

Wearing CW-protective combat clothing results in a significant and important increase in serious dehydration. Previous reviews have reported that, during hot conditions, dehydration will occur within 1 hour or less when the individual is engaged in physical activity, so enforced drinking is mandatory for health maintenance (Taylor and Orlansky, 1987). Wearing CW-protective combat clothing during the nuclear/chemical segment of CANE I produced clinical dehydration in almost one-fifth of the soldiers after 72 hours (Draper and Lombardi, 1986). During this same period 83 percent showed significant signs of dehydration (equivalent to 24 hours without fluid intake). It is important to note that the 20 percent who were seriously dehydrated were not aware of their dehydrated condition. An evaluation of Army aviators on extended helicopter operations for a period of 6 continuous days (12 hours in MOPP 4 and 12 hours in MOPP 1) indicated that an average of 5 liters of water intake per 24 hours was required.

Even when heat stress was not an important factor, the performance of many combat and combat support tasks in all combat arms was degraded when CW-protective combat clothing was worn. The performance degradation was due to reduced manual dexterity, reduced vision, reduced communication, respiratory stress, and psychological stress. This conclusion is supported by a number of studies reviewed in the present paper as well as previous reviews (Taylor and Orlansky, 1986, 1987).

A paper by Taylor and Orlansky concluded that "detection of targets and the accuracy of fire are significantly degraded when protective masks are worn" (Taylor and Orlansky, 1987, pp. IV-1 and IV-27). As reviewed in the present paper, platoon performance for almost all measures of close combat, heavy, was degraded during combined arms exercises (CANE I) when CW-protective combat clothing was worn (Draper and Lombardi, 1986). The number of targets detected, engaged, and killed was significantly degraded. Direct fire engagements were degraded by 52 percent for all weapons and engagements for the M16 decreased by 59 percent; battle intensity (shots fired per minute in attack) was degraded by 69 percent; engagement range for the M60 machine gun was increased by 52 percent; the engagement of friendly forces was increased by 360 percent. In a series of studies involving armor crews, the time of target engagement increased during continuous operations in MOPP 4 (Ellis et al., 1986; Glumm, 1988). Ellis et al. (1986) reported that target engagement times increased in two studies in a tank turret trainer, in a study involving a combat scenario in a stationary tank, and in a combat scenario involving a platoon of four tanks operating against opposing force. The time increased was found to be linear.

During a combined arms exercise, the duration of battle was increased 82 percent and the loss-exchange ratio (killed attackers/killed defenders) was increased by 66 percent from 2.40 in baseline to 3.99 in the nuclear/chemical environment--an unacceptable level according to current Army doctrine. Army doctrine states that a 3:1 ratio is usually necessary to conduct a successful attack.

Command and control during combined arms exercises was significantly degraded by wearing CW-protective combat clothing (Draper and Lombardi, 1986). Commander casualties increased 34 percent during attack and the time to replace commanders increased by 343 percent. It was more difficult to direct fire, maneuver the unit, and maintain unit orientation at the platoon level.

In a review paper, Taylor and Orlansky (1987) reported that CW-protective combat clothing degraded communication but the magnitude of the effect had not been adequately documented. Combined arms exercises reviewed in the present paper indicate that communications were significantly degraded by wearing CW-protective combat clothing (Draper and Lombardi, 1986). Both the frequency and duration of radio messages increased about 50 percent. Calls for indirect fire increased over 200 percent.

A combined arms exercise demonstrated that minimum training of the combat platoon in decontamination procedures prepares the platoon to assist a dedicated chemical

decontamination squad to decontaminate vehicle and platoon equipment. Decontamination of platoon personnel and personal equipment was accomplished without assistance of the chemical decontamination squad. This finding provided a test of a change in Army doctrine regarding decontamination and reduced the workload for chemical decontamination combat support with a resultant force structure reduction. There was a need for some additional training of the combat platoon with agent stimulants since some of the platoon would have received skin contamination.

A previous review (Taylor and Orlansky, 1987) also indicated that manual dexterity tasks such as disassembly/assembly of small arms are significantly degraded by wearing CW-protective combat clothing (masks and gloves). During a series of field studies involving Army personnel, performance on maintenance tasks requiring both gross and fine motor skills was significantly degraded by wearing CW-protective combat clothing. Montgomery (1987) estimated that gross motor skills were degraded by about 30 percent while fine motor skills were degraded by about 60 percent. Using Montgomery's data, the percent time decrement (D_T) for seven maintenance tasks while wearing CW-protective combat clothing ranged from −26 to −39 percent. Shipton, Beilstein, Chenzoff, Pitzer, and Joyce (1988) also conducted a field study using Air Force personnel to evaluate the performance degradation of maintenance tasks due to CW-protective combat clothing. Seven of 26 tasks were severely degraded by wearing CW-protective combat clothing. The average percent time degradation (D_T) for the 26 tasks was −30.7 percent. The experienced maintenance technicians preferred 7-mil or 14-mil gloves which they reported to provide better tactility and finger dexterity than the standard 22-mil glove. It was noted, however, there were some compromises which ranged from small punctures to large cuts and holes in the new gloves. Laboratory studies on standard psychomotor tests indicated that the CW-protective butyl rubber gloves significantly reduced manual dexterity. A laboratory study also indicated that medical specialists wearing CW-protective gloves had performance decrements when compared to BDU.

During a field trial, HAWK missile operations were significantly degraded due to wearing MOPP 4. Lack of prior training on the tasks by the assault fire units limited interpretation of the data. There was a compounding of learning to perform the task and adapting to wearing MOPP 4.

Two field trials to determine the effects of wearing MOPP 4 on the performance of night reconnaissance missions were reviewed. In one study there was insufficient data to conduct a statistical analysis. Ordering the data by trials indicated that there was an

improvement over trials but the effects of learning the task and learning to adapt to MOPP 4 were confounded. In the second study, a regression analysis indicated that it required 10-50 percent longer to accomplish the tasks in MOPP 4 than in BDU. In both studies, stealth was totally lacking due to high noise, slow movement, poor spacing, and poor use of protective cover.

In investigating the psychological effects of sustained operations under simulated chemical warfare conditions, a number of field studies have found that symptom intensity increased during the test and there was a general deterioration of mood. During field tests, subjects have been categorized (post hoc) as casualties and survivors. Casualties are defined as subjects who voluntarily withdrew or who were withdrawn by the medical team. Significant differences on a series of psychological tests were found between the two post hoc groups in the intensity of perceived symptoms and on mood factors (clear thinking, fatigue, friendliness, and dizziness). Discriminant analysis indicated that based on psychological test scores, a symptom-based classification routine correctly identified 94 percent of the subjects as members of their respective post hoc groups. The coping-based classification correctly identified 98 percent of the cases.

When heat stress is not a significant factor, Taylor and Orlansky (1987) reported that, with training in CW-protective combat clothing, individuals and crews will modify procedures to reduce performance decrements caused by MOPP 4. Studies reviewed in the present paper also indicate that training in CW-protective combat clothing can reduce the amount of performance decrement of individuals and units performing combat and combat support tasks. Draper and Lombardi (1986) reported that the amount of prior CW-defense training of the platoon leader was an important variable affecting overall platoon performance in a simulated CW condition. This variable was important even when the other members of the platoon had little CW-defense training.

Taylor and Orlansky (1987) reported that:

> . . . while many of the studies reviewed in this report have emphasized the need for increased training in the use of chemical protective clothing, the Grand Plot III field trial was the only study specifically designed to directly measure performance improvement as a result of training. This study was concerned with twelve chemical defense tasks common for all soldiers. It is important that additional studies and field trials be conducted in order to determine more precisely the effects of training on mission effectiveness in simulated chemical environments. These trials are needed not only to determine deficiencies in current training, but also to determine ways to increase current combat readiness.
>
> --Taylor and Orlansky, 1987, pp. III-13

Montgomery's analysis (1987) indicated that degradation on maintenance tasks involving gross motor skills could be reduced by about a third, from 30 to 20 percent, through regularly scheduled training in MOPP 4. He also reported that degradation on fine motor skills used in performing maintenance tasks could be reduced from 60 to 50 percent or less through training in MOPP 4. He indicated that "adaptation to and functioning in MOPP improved with each additional try" (Montgomery, 1987). We calculated from data by Johnson and Sleeper (1986) that practice of manual dexterity tasks for 5 days while wearing CW-protective combat clothing produced an improvement of 33 percent on two standardized psychomotor tests. Six days of practice of performing medical tasks in MOPP 4 by medical specialists, resulted in substantial improved performance. This result, however, was confounded with learning to perform the tasks. Taylor and Orlansky (1987) reported that training increased proficiency on tasks required for personal survival in a CW-defense situation. For many tasks the knowledge and skill needed to adequately use CW-protective combat clothing can be acquired during brief refresher training. They reported one study which found that as little as 2 days' training significantly improved performance.

Taylor and Orlansky (1987) reported that only one of 21 studies reviewed was designed to quantify the effects of training in reducing the degradation due to wearing CW-protective combat clothing. One of the objectives of a number of the field studies reviewed in the present paper was to determine the impact of training in MOPP 4 on reducing the performance decrement caused by wearing CW-protective combat clothing (Wick and Morrissey, 1987; Parker, Stearman and Montgomery, 1987; Parker and Stearman, 1987; Ramachandran and Montgomery, 1987; Montgomery, 1987; and Wick, Morrissey and Klopcic, 1987). In none of the studies, however, was a stable baseline performance established in battle dress uniform prior to determining performance decrements due to wearing CW-protective combat clothing. None of the teams and/or individuals was well trained in the tasks to be performed. The tasks in all of the studies were repetitive and performance improved with repeated practice for both BDU and MOPP 4 trials.

In a number of the studies meaningful comparisons could not be made between BDU and MOPP 4 due to lack of data For example, Ramachandran and Montgomery (1987) reported that:

> . . . it was intended that the testing would provide valuable information on the efficiency of the performance of troops in chemical protective gear, however, the data obtained were not sufficient to make any conclusive interpretations, primarily because there was insufficient trials to subject the results to statistical evaluation. (p. 4)

They further indicated that

> . . . since learning and adaptation occurred each time a team performed a task, it was impossible to identify statistically the specific performance degradation due to MOPP 4. However, such an analysis could have been possible if the trials had been repeated with more soldiers who were familiar with the performed tasks. (p. 5)

They found that the "time required to perform both movement and skill tasks improved when experience was gained in MOPP 4 gear" (p. 7) and ". . . as the teams become familiar with the tasks and the course, the time taken for the completion of each task became shorter and shorter irrespective of the attire" (p. 7). In others, there were not enough subjects to permit inferential statistics. In all of the above studies, extensive field experiments were conducted without an appropriate experimental design. Consequently, the results of the studies are difficult to interpret in terms of the two principal objectives: (1) the amount of performance decrement due to wearing CW-protective combat clothing, and (2) the effect of training in reducing performance decrement.

Shipton, Chenzoff, Joyce, Deibel and Weimer (1988) also demonstrated that practice in performing 10 F-16 maintenance tasks while wearing CW-protective combat clothing improved performance on the tasks (training effect). An earlier study by Shipton, Beilstein, Chenzoff, Pitzer and Joyce (1988) had found that the CW ensemble seriously degraded performance of these tasks. Since data concerning baseline performance in fatigues was not stable, the data concerning the training effect while wearing CW clothing were confounded with the effect of learning to perform the task as individuals. The same conclusion can be drawn for the four tasks performed by two-person teams. The training effect was further confounded by "interventions," i.e., workaround procedures; modifications to aircraft, AGE, and tools; and job guide changes.

The studies reviewed by Taylor and Orlansky (1987) and in the current paper clearly indicated a wide variation of the amount of performance degradation due to wearing CW-protective combat clothing depending on the combat or combat support tasks. Nevertheless, a general finding was one of significant performance degradation of individual and unit performance.

A growing body of evidence indicates that there is inadequate training in the use of CW-protective combat clothing. In 1987 Knapp and Orlansky reported that:

> . . . (a) the effectiveness of CWD training is not adequate, raising doubt that the armed forces could survive and accomplish their assigned missions in a chemically contaminated environment, and (b) the limited amount and extent

> of CWD training is due primarily to the relatively low priority given to CWD training by military commanders at all levels. (p. 51)

Ramachandran and Montgomery (1987) recommended that "all military exercises should be tested in a simulated chemically contaminated environment. Each task should be repeated until no further improvements in efficiency can be maintained" (p. 16). Johnson and Sleeper (1986) recommended that soldiers be given intensive training in job-specific tasks while wearing CW-protective combat clothing, especially if the task requires a significant amount of manual dexterity.

A Navy survey was conducted by Moskal, Driskell, and Carson (1987) to determine the knowledge level of Navy personnel with regard to chemical defense. The results indicated that almost 50 percent of the 333 Navy personnel from 16 ships to which the questionnaire was administered had not been involved in any shipboard chemical defense exercise. Only 7.5 percent of the personnel tested were able to answer the 11 items of the questionnaire that were considered critical to survival under chemical warfare conditions. Forty-eight percent reported that they had not participated in any shipboard chemical defense exercise. Two-thirds reported that they had worn the mask during the past 3 months. Seventy-two percent reported that the last time they wore the mask was on board ship. Only 17 percent reported that they had worn CW-protective combat clothing for longer than 60 minutes at any time during their career. One of the Navy's operating standards requires that proficiency be demonstrated in performing General Quarters watch station duties while wearing CW-protective combat clothing and equipment continuously for at least 6 hours or longer (if feasible). The data indicated that less than 5 percent of the personnel surveyed had *ever* worn full CW-protective combat clothing for more than 3 hours. The number of personnel who have worn CW-protective combat clothing while standing watch under General Quarters was not determined by the survey but was estimated to be about 5 percent.

The report concludes that a critical need exists for further training of CW common skills, i.e., the skills that all personnel need to know to protect themselves independent of the special skills that may be needed because of a particular job. At that time (1987) the Navy had no training site with the responsibility for training all hands in CW common skills. During recruit training, a 3-hour period is devoted to chemical defense familiarization, but it does not cover training of CW common skills. Subsequent to recruit training, the vast majority of Navy personnel receive no further formal CW training. Certain ratings received additional training and there is a 5-day Basic CBR Defense Course

which has the equivalent of 1.7 days of chemical defense-related training. The input for this course in FY1986 was 2,382 (Knapp and Orlansky, 1987, p. 20).

According to the report by Moskal, Driskell, and Carson (1987), Navy enlisted personnel do not possess the knowledge of CW basic defense procedures needed to perform common survival skills. With 285,000 Navy combat personnel in 1987, the throughput for the Basic CBR Defense Course would have to be increased by 100-fold over the FY1986 input to provide CW common skills training for Navy combat personnel in 1 year. Without this knowledge among its enlisted personnel, one must conclude that the Navy would be unable to accomplish its assigned mission under chemical defense conditions. A significant deficiency appears to exist in the state of readiness for a chemical attack against U.S. Navy ships.

The growing availability of networked simulators, such as SIMNET, provides an opportunity to conduct battalion-level, two-sided engagements under experimental conditions (Orlansky and Thorpe, 1991). Thus, it now becomes possible to collect reliable data on performance in simulated combat arms exercises, wearing CW-protective combat clothing, that can significantly extend what is now known reliably only in laboratory studies. Since networked simulation provides such data as weapons killed and exchange ratios used in most combat models, one should be able to estimate more precisely the military value (and/or penalty) attributable to wearing CW-protective combat clothing and of training to achieve maximum benefit of its use.

V. CONCLUSIONS

Based on the studies reviewed in this paper, the following conclusions are warranted:

1. Heat stress, due to wearing CW-protective combat clothing, seriously degrades human performance. This finding is supported by many studies reviewed in this paper and in previous papers by Taylor and Orlansky (1986, 1987). Under some conditions, performance will degrade significantly within 1 hour. Endurance can be extended, if ambient work-place temperatures are not severe, by enforced drinking of water and by frequent rest periods. Heat stress effects have been modeled by Goldman and associates at the U.S. Army Institute for Environmental Medicine (USARIEM). The model accurately predicts (± 10 percent) the human metabolic heat production of soldiers when level of encapsulation, environment, physical condition of troops, combat mission (including duration), physical activity and work/rest cycles, can be accurately specified.
2. Even when heat stress is not a significant factor, the performance of many combat and combat support tasks in all combat arms is degraded when CW-protective combat clothing is worn. This degradation is due to reduced manual dexterity, reduced vision, reduced communication, respiratory stress, and psychological stress. This finding is supported by a number of studies reviewed in the present paper as well as previous reviews by Taylor and Orlansky (1986, 1987).
3. Field studies on endurance of combat crews in armor, mechanized infantry, artillery, and aviation operating in CW-protective combat clothing and involved in continuous operations have indicated that crews will have difficulty sustaining effective combat operations even when heat exhaustion is not a significant factor. In most of the field studies many crews of combat units have become operationally ineffective due to voluntary withdrawal of individual crewmembers from the test.
4. During a combined arms exercise, the duration of battle was increased 82 percent and the loss-exchange ratio (killed attackers/killed defenders) was increased by 66 percent, from 2.40 in the baseline condition to 3.99 in the CW environment. This loss-exchange ratio is unacceptable according to current Army doctrine.

5. The detection of targets, the engagement times and the accuracy of fire are significantly degraded when CW-protective combat clothing is worn. This finding is substantiated by a number of studies reviewed in this paper including combined arms exercises, and continuous operations field trials. In a number of studies involving armor crews, increased target engagement times are a linear function of time of operations in MOPP 4.

6. Command and control, and communications are significantly degraded by wearing CW-protective combat clothing. This finding has been substantiated in recent combined arms exercises.

7. Wearing CW-protective combat clothing results in a significant and important increase in serious dehydration. During hot conditions dehydration will occur within 1 hour or less when the individuals are engaged in physical activity, so enforced drinking is mandatory for health maintenance.

8. Manual dexterity tasks requiring both gross and fine motor skills are significantly degraded by wearing CW-protective combat clothing (masks and gloves). This finding is substantiated by studies involving disassembly/ assembly of small arms and involving a substantial number of maintenance tasks. The use of 7-mil or 14-mil gloves instead of the standard 22-mil glove provides better tactility and finger dexterity, but these thinner gloves appear to be more prone to compromise.

9. Wearing CW-protective combat clothing produces a variety of psychological effects including increased symptom intensity and general deteriation of mood. These findings are supported by a number of laboratory and field studies.

10. Recent laboratory studies suggest differences between males and females in physiological tolerance to heat stress with female tolerance being lower, but this finding has not been established incontrovertibly.

11. The studies reviewed previously (Taylor and Orlansky, 1987) and in the current paper clearly indicated that the amount of performance degradation due to wearing CW-protective combat clothing varies widely with the combat, combat support, or combat service support task to be performed. A general finding, however, was a significant performance degradation of individual and unit performance.

12. With training in CW-protective combat clothing, individuals and crews learn to modify procedures and consequently reduce the negative effects of wearing CW-protective combat clothing when heat stress is not a significant factor. A number of studies has indicated that training in CW-protective combat clothing can reduce the amount of performance decrement of individuals and crews performing combat, combat support, and combat service support tasks.

13. In a simulated CW-combined arms exercise the amount of prior CW-defense training of the platoon leader was an important variable affecting overall platoon performance even when other platoon members had little CW-defense training.

14. Many studies reviewed in this and previous papers (Taylor and Orlansky, 1986, 1987) have emphasized the need for increased training in the use of CW-protective combat clothing. Only one study of the 21 reviewed by Taylor and Orlansky (1987) was designed to quantify the benefits of training under simulated CW conditions.

15. An objective of a number of field studies reviewed in the present paper was to determine the impact of training in MOPP 4 on reducing the performance decrements caused by wearing CW-protective combat clothing. These studies failed to achieve this objective since none established stable baseline performance in the battle dress uniform prior to determining performance decrements due to wearing CW-protective combat clothing. In addition, none of the teams and/or individuals was well trained in the tasks to be evaluated. Consequently, performance improved with repeated practice for both BDU and MOPP 4 trials.

16. For a number of studies reviewed, meaningful comparisons between BDU and MOPP 4 could not be made due to lack of data, an insufficient number of subjects, or poor experimental design.

17. A growing body of evidence indicates that there is inadequate training in the use of CW-protective combat clothing. This is supported by a review by Knapp and Orlansky (1987) and a Navy survey conducted by Moskal, Driskell and Carson (1987). The latter report concludes that a critical need exists for further training of CW common skills, i.e., the skills that all personnel need to know to protect themselves under CW conditions.

18. The growing availability of networked simulators, such as SIMNET, provides an opportunity to conduct battalion-level, two-sided engagements under experimental conditions. Thus, it now becomes possible to collect reliable data on performance in simulated, combat arms exercises, wearing CW-protective combat clothing, that can significantly extend what is now known reliably only in laboratory studies. Since networked simulation provides such data as weapons killed and exchange ratios used in most combat models, we should be able to estimate more precisely the military value (and/or penalty) attributable to wearing CW-protective combat clothing and of training to achieve maximum benefit of its use.

VI. RECOMMENDATIONS

Based on the studies reviewed and on the conclusions, the following recommendations are made:

1. In 1987, Taylor and Orlansky recommended "since only one study, the Grand Plot III field trial was designed to measure the amount of performance improvement due to training, it is recommended that future studies and field trials directly investigate the benefits of training. It is important to develop a more extensive documentation of the effects of training on mission effectiveness in simulated CW environments" (Taylor and Orlansky, 1987, pp. V-1). While a number of recent studies have had as an objective to determine the effects of training on improving individual and crew effectiveness in CW environments, methodological problems have limited the effectiveness of these studies. Consequently, this recommendation remains valid.

2. For studies designed to determine the effects of training on improving individual and crew effectiveness in CW environments, the individuals and crews should be well trained in the tasks to be performed. A stable baseline (in BDU) should be established prior to the introduction of CW-protective combat clothing (MOPP 4). Enough subjects should be used or trials conducted to permit statistical comparisons between baseline and experimental conditions, and to permit inferential statistics with enough "power" to enable the results to be used with confidence. After introducing the experimental condition, enough trials should be conducted in CW-protective combat clothing to determine the effect of training in MOPP 4.

3. Performance decrements due to severe conditions are unavoidable but their impact can be delayed as well as reduced by appropriate training. The Desert Storm experience, not examined in this study, can provide important data on the performance of troops wearing CW-protective clothing on their arrival in theater and the effect of training in improving their performance. We strongly urge that the lessons learned there about the effect of wearing CW-protective clothing and the effectiveness of training in its use be carefully reviewed.

4. The experimental data comparing male and female differences in performance to heat stress while wearing CW-protective combat clothing is extremely limited. In view of the increased numbers of females involved in combat support and combat service support roles and the potential of females being involved in combat situations in which a substantial CW threat exists, this area warrants increased research emphasis.

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APPENDIX A

MISSION DEGRADATION TROOP TEST

Source: Carr, Kreshner, Corona, and Jackson (1980)

APPENDIX A—MISSION DEGRADATION TROOP TEST

Test	Year	Unit	Mission	Temperature	Location	MOPP*	Results
JACKPOT	1959	48 Individuals	Typical tasks	81-93 F	Ft. McClellan	Full MOPP	Strenuous activity cannot be performed in 2 layer CC-2 impregnated clothing, suit, gloves and hood without 40% casualty rate from heat exhaustion. With prolonged wear, additional casualties come from friction and abrasion rashes.
(Including PROTECT 1)	1959	Individuals and 2-man teams	10 skills	84-100 F	Ft. McClellan	Up to full MOPP	There is no danger to health while wearing permeable protective ensemble unless safeguards are taken. Troops can perform in full protection if they pace themselves. Use of protective equipment degrades performance. Full protective outfit can be worn for 3 days if there are unprotected breaks for food, water, and elimination.
ROAD VOL I Battalion	1963	Individual up to Mech BN	Individual tasks up to Mech BN opns (attack, defend, retrograde)	Various WGBT ranges 30-90 F	Panama, Ft. Ord, Hunter-Liggett	Up to full MOPP	Operating in a toxic environment for a prolonged period results in progressive unit ineffectiveness; CB protective equipment itself produces no significant reduction in performance until physical and mental degradation occur; stay-times (times a unit can remain in toxic environment) vary with energy expenditure and climatic conditions; there is a need for a realistic toxic stimulant.
VOL II	Mech Rifle Co.	Defend				APC	It is feasible to use APC for rest, CP, aid station.
SAMPLES	1963	Individuals (selected from 3 companies)	Tactical exercises, assault, and bivouac		Ft. McClellan	Mask	Improvement in use of masks is attainable by concentration on human factors such as leadership, motivation, and training.
Interim Toxic Environment	1967	Forward observer and 7-man Inf Element	Target detection fire adjustment	Low 50's-High 90's F	Hunter-Liggett	Mask, Hood, Gloves	Mask, hood, and gloves impair performance.
METOXE II	1969	Reinforced Mech Rifle Co.	Attack, defend, retrograde	59-89 F	Ft. Carson	Full MOPP	Dismounted mobility degraded unacceptably; existing organization inadequate for CBR operation; doctrine, techniques, procedures for decontamination unacceptable; XM51 shelter effective but degraded unit effectiveness; there is need for realistic training agent.
69-10	1969	Battalion Landing Teams	Amphibious Assault	82-89 F	Isle de Vieques, P.R.	Full MOPP	Amphibious assault is not feasible in full MOPP in tropics.
METOXE I	1971	Maintenance Elements	Support Tasks	50-82 F	Ft. Riley	Full MOPP less overboots	Degradation occurs in representative maintenance task; training is essential for performance in MOPP; protective glove unsuitable; well trained maintenance personnel can perform in protective clothing under toxic conditions.
GRAND PLOT III	1975	Infantry squads; aviators	Marches, attack defense, fire mission	WBGT range 70-84.9 F	Hunter-Liggett	Up to full MOPP	Degradation increases with MOPP.
ILL WIND	1977	Tactical Operations Center (TOC)	BN TOC actions, relocate	Warm and dry to hot and humid	Ft. Benning	Use of M51 vs. full MOPP less overboots	MOPP degrades performance. M51 provides satisfactory work environment for TOC.
XM-29 AH-15	1978	Helicopter Pilots	Various Maneuvers	WBGT Index 70-84.9 F	Ft. A.P. Hill	Mask (XM29, M24)	Some degradation occurs; pilots prefer XM29.

*MOPP: Mission Oriented Protective Posture. Full MOPP indicates wear of mask, hood, over-garment or liner, gloves, and overboots (MOPP 4).)

APPENDIX B

OPERATIONAL DEGRADATION DUE TO CHEMICAL PROTECTION IN FIELD TRIALS WITHOUT HEAT STRESS

Source: Goldman (1981)

APPENDIX B—OPERATIONAL DEGRADATION DUE TO CHEMICAL PROTECTION IN FIELD TRIALS WITHOUT HEAT STRESS

	Fire Power			Communications			Mobility			Support		
*MOP	I	II	III	I	II	III	I	II	III	I	II	III
INFANTRY												
		Rounds per hit		Messages unanswered			Road march time			Time to get medic		
M-14	5.4	5.9	8.6	4	-	10	-	-	12%			270%
(96)	-	9	59	Time to install wires			March rate			M-14 maintenance		
M-60	10	5.7	10.7	15'	25'	26 min	-	<4%	10%			14%
(96)	-	43	79	Getting specific man			Assault time			CBR recon		
M-79	5.3	3.0	8.4	1-2'	-	4% min.	-	<10%	>100%	4 min.	-	9.5 min.
(96)	-	43	58	Voice versus hand signals			platoon leader		142%	Ammo resupply		
							First man		197%	13 min.	30%	47%
							last man		102%			
ARMOR: NB-MOP III also required closed hatch												
		Rounds per hit		Target identification:			Road march time		9%	Boresight		1 min.
M-73	-	NSD	-	missed			March rate		13%		Complaints	
M-83	-	6%	104%	1	7	25	Attack time		20%	Gloves:	33%	maintenance
											27%	loading
105	-	0.3	0.6	13%	28%	42%	Attack difficulty		3X	Mask Hood:	20%	vision
		Zero main gun		of transmissions						CBR suit:	14%	movement
	-	1 min.	3 mi	-	19	28						
				duration of transmissions								
				-	122	4%						
ARTILLERY:												
Time from receipt at FDC to battery order				In firing sections			Last Unit			Filling sandbags		
Area adjust	-	27%	137%	responses			across sp		192%	22 min.	25'	35'
Registration	-	100%	75%	26 OK	11%	24%	Clear hasty position		45%	Wire splicing		
										5.5 min	7.75'	8'
Transfer	-	33%	94%	Accuracy			Enter-to-all-ready					
				>95%		45%			31%			
Target Location F.O. i.d. to call for fire				F.O. i.d. to end of mission								
	90 sec	114 sec	183 sec	27 min	-	40 min.						

Engineer road repair, bridge building, demolition – NSD; voice commands repeated 2X as often in MOP III.

*MOP I Normal combat clothing.

MOP II Protective ensembles with masks but without hood, gloves, and with all apertures open

MOP III Fully encapsulated with mask, hood and gloves. MOP III corresponds to current MOPP 4.

APPENDIX C

EMPIRICAL STUDIES OF THE EFFECT OF CW-PROTECTIVE COMBAT CLOTHING ON PERFORMANCE

APPENDIX C--EMPIRICAL STUDIES OF THE EFFECT OF CW-PROTECTIVE COMBAT CLOTHING ON PERFORMANCE

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
1. Combined Arms Exercise (Mechanized Infantry Platoons)	BDU and MOPP 4	Agent: None Scenario: Comparison of BDU (Baseline) with MOPP 4. Evaluated mechanized infantry platoons operating for 72 hours on conventional and integrated battlefield using a series of force-on-force trials. Environment: Mostly cool to mild temperatures, but some days warm. Fort Hunter-Liggett, CA, March-May, only 5 heat stress casualties (mild). Duration: Two operations of 72 hours each, one baseline, one in simulated chemical environment. 12 hours continuous in MOPP 4. Subjects: Eight FORSCOM Platoons. Training: Relatively minimal training in MOPP 4. Few players were trained for periods longer than 6 hours and the mean was less than 3 hours. Design: Force-on-force comparisons of BDU vs. MOPP 4. No statistical analysis. Means only.	(a) Close combat, heavy. (1) Direct fire engagements; (2) Fratricidal engagements; (3) Ammunition expenditures; (4) Percentage of threat targets engaged once; (5) Percentage of threat targets killed; (6) Duration of battle; (7) Friendly losses; (8) Loss exchange ratio (b) Command and Control (1) Commanders assessed as casualties; (2) Time to replace killed commanders (c) Communications (1) Radio messages-frequency duration (d) Fire Support (1) Calls for Fire support (e) Air Defense (1) Amount of camouflage action.	Comparison of Baseline (BDU) with MOPP 4 (a) Close Combat, heavy. (1) Direct fire engagements decreased 52%; (2) M16 engagements decreased 59%; (3) Engagement efficiency decreased 27% from 83% to 61%; (4) Battle intensity (number of shots/min.) decreased 63%; (5) Decreased average engagement range for M60 machine gun increased by 52%; (6) Fratricidal engagements increased 360% from 4.3% to 19.8%; (7) Ammunition expenditure (trigger pulls) decreased 43% (attack) and 22% (defense); (8) Percentage of threat targets engaged once, decreased 25% from 72% to 54%; (9) Percentage of threat targets killed decreased 22%, from 54% to 42%; (10) Duration of battle increased 82%; (11) Friendly losses increased 32% (infantry) and 138% (APC); (12) Loss Exchange Ratio increased 66% from 2.4 to 3.99. Army doctrine requires at least a 3:1 ratio for a successful attack (b) Command and Control (1) Commanders assessed as casualties - 34% in attack; (2) Time to replace killed commanders (c) Communications (1) Radio messages frequency increased 47% and duration increased 53% (d) Fire Support - Effectiveness could not be quantified. Dependence on indirect fire support increased dramatically (e) Air Defense. Camouflage action degraded 15% first day, 30% second day and no action on third day.	(From Draper and Lombardi) 1. Most instrumented data for 3 of 8 platoons lost. 2. The 3-to-1 attacker to defender ratio was not maintained. 3. Inexperienced evaluators were used. Data of questionable quality. 4. Chemical casualty assessment was not conducted. 5. Weapons effects simulation not entirely realistic.	Draper and Lombardi (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measures	Findings and Recommendations: Task	Degradation	Critical Comments	Study
2. Field Trial (Maintenance Tasks)	BDU/ MOPP 4	Agent: None Scenario: Time for maintenance teams to accomplish various maintenance tasks was compared for BDU and MOPP 4. The maintenance tasks were: (1) remove and replace M60A3 tank power pack; (2) remove and replace M60A3 tank transmission; (3) remove and replace M109 howitzer breechblock; (4) recover M60A3 tank; (5) repair M60 machine gun; (6) repair M109 howitzer traverse mechanism; (7) repair FADAC printed circuit board. Environment: 1984 Tests 7° to 28° C 1985 Tests 14° to 32° C. Duration: April and May 1984, and July and August 1985. Subjects: Soldiers from the student brigade of ordnance center and school. Training: Subjects were trained in the appropriate military operational specialty (MOS); crew members had no previous experience working together. Design: Comparisons of times in BDU and MOPP 4. Ad hoc decision to use regionalized statistics.	Time to complete maintenance task.	1. R&R M60A3 Tank Power Pack	35% ± 20%	Teams and/or individuals were not well trained in the tasks to be performed. A stable performance baseline in BDU was not established prior to the introduction of MOPP 4. For some tasks, lack of data prevented statistical analysis. For none of the tasks were enough trials conducted after the introduction of MOPP 4 to determine the effect of training in MOPP 4 although this was an objective of the field trial.	Wick and Morissey (1987); Parker, Stearman and Montgomery (1987) and Montgomery (1987).
				2. R&R M60A3 Tank Transmission	50%		
				3. R&R M109 Howitzer Breechblock	25% ± 25%		
				4. Recovery of M60A3 Tank	lack of data		
				5. Repair of M60 Machine Gun	0		
				6. Repair of M109 Howitzer Traverse Mechanism	50% ± 30%		
				7. Repair of FADAC Circuit	lack of data		

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
3. Field Trial (Night Reconnaissance)	BDU and MOPP 4	Agent: None. Scenario: Comparison of BDU with MOPP 4 during a simulated night reconnaissance mission. Environment: Moderate to warm (52° to 84° F). Hours of darkness. Duration: 8h/night for three nights. Subjects: Twelve Marines (3 teams of four each). Training: None prior to test. Design: One trial conducted by each team in BDU and two trials in MOPP 4. Order was balanced as follows: Trial Order Team — 1st — 2nd — 3rd 1 — MOPP 4 — BDU — MOPP 4 2 — MOPP 4 — MOPP 4 — BDU 3 — BDU — MOPP 4 — MOPP 4	Time to complete six tasks: (1) route reconnaissance, (2) photo of target, (3) emplacement of claymore mine, (4) air and water sampling, (5) sketch of dam, (6) movement between objectives. Questionnaire of difficulties caused by individual components of MOPP gear.	The data from the trials were insufficient to perform statistical analyses. Learning to perform the task and adaptation to MOPP 4 conditions occurred on each of the three trials. Due to the design, the results of learning and adaptation were confounded such that performance degradation due to MOPP 4 could not be identified. Ordering of the results by trial by condition (BDU and MOPP 4) permitted a meta-analysis which indicated that the difference between performance in MOPP 4 was 150 to 200 percent longer than in BDU. Performance in BDU improved over 3 trials by about 65% but improvement in MOPP 4 (average of two teams) by trial improved 5 to 10 percent. Questionnaire data indicated that heat build-up was the primary problem. Perspiration in the mask, seal compressed and created problems breathing. Boots were a problem—slipping, snagging. Voice communication poor. Stealth totally lack.	Failure to achieve stable performance on night reconnaissance task prior to the use of MOPP 4 resulted in inability to determine decrement due to MOPP 4. Design was also inadequate to determine the effect of training on reducing decrement to MOPP 4.	Ramachandran and Montgomery (1987), Wick, Morrissey, and Klopcic, (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
4. Field Trial (HAWK Missile)	BDU and MOPP 4	Agent: None. Scenario: Comparison of performance in BDU and MOPP 4 of Marine assault fire units emplacing HAWK Missile equipment in preparation for firing, disassembly and preparation for movement. Three units at two locations: Yuma and Cherry Point. Environment: Yuma: 44°- 78° F with norm of 63° to 68° F, 40-50% RH early morning decreased to 20% RH by noon. Cherry Point: Early morning 70° F increasing to 90° F or above before noon; RH 100% early morning decreasing to 50% by noon. Daylight. Duration: Three consecutive days. Subjects: Six Marine assault fire units, 3 each from Yuma (N = 26) and Cherry Point (N = 27). Design: The order of performing the operation for the three units at each site is as follows: Order of Condition Unit — 1st Day — 2nd Day — 3rd Day 1 — BDU — MOPP 4 — MOPP 4 2 — MOPP 4 — BDU — MOPP 4 3 — MOPP 4 — MOPP 4 — BDU Kruskal-Wallis-LS-sample test used to test for differences among the nine cells for each of the 42 tasks conducted at each site. The two-way analysis of variance (ANOVA) for unequal numbers of observations/cell (unit by condition). Mann-Whitney U test used to compare means for statistically significant factors.	(1) Times to emplace following equipment and the trials to perform the tasks for each piece of equipment: (a) Platoon Command Post, (b) High Power Illuminator Radar, (c) Continuous Wave Acquisition (radar), (d) Launcher, (e) Pulse Acquisition Radar (42 total tasks). (2) Total Time of Operation (not cumulative time for each task). (3) Observation of damaged equipment. (4) Questionnaire regarding problems of operating in MOPP 4.	Kruskal-Wallis test indicated a significant difference in performance times for 34 of 42 tasks at Cherry Point and 39 of 42 at Yuma. The ANOVAs indicated a significant difference related to (1) conditions for 5 tasks at Cherry Point and 9 tasks at Yuma; (2) Units for 10 tasks at Cherry Point and 13 at Yuma; (3) interaction between conditions and units for 22 tasks at Cherry Point and Yuma. "An examination of the interaction of the times to perform shows a relationship between longest times and first performance regardless of conditions."	The subjects in the study were not trained to a stable baseline prior to testing in MOPP 4.	Parker and Stearman (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Types of Measures	Findings and Recommendations	Critical Comments	Study
5. Field Trial (Armor)	BDU/ MOPP 4	Agent: None Scenario: Conducted during a scheduled training exercise. Comparison of mission performance in BDU (baseline) and MOPP 4 for: (1) planning and preparation for defense; (2) movement from assembly area to battle positions; (3) enemy engagement; and (4) consolidation. Environment: Temperature ranged from 7.6° to 28.2 °C (45.7° to 82.8° F). Duration: From October 22-November 2, 1984. Trials were 5-6 hours in duration in MOPP 4. Subjects: Four-man crews, three-tank platoons. Training: Unknown Design: Nine trials–three for each platoon, three in BDU and six in MOPP 4. Mann-Whitney U Test was used to test significance.	Time to complete 15 tasks in BDU/ MOPP 4.	Platoons were able to complete all tasks except bounded overwatch and boresighting of machine gun without time degradation. Authors recommended that armor units should emphasize training under CW conditions.	No baseline in BDU was established. Two platoons conducted the trials in BDU first and the third platoon conducted the trials in BDU for the third trial. Small data set.	Barry, Stack, Henry, Enright, and Welch (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measure	Findings and Recommendations	Critical Comments	Study
6. Field Trial (Communications)	BDU/ MOPP 4	Agent: None Scenario: During a scheduled field training exercise, tactical teams set up and broke down communication equipment and they typed word lists to simulate message traffic in BDU and MOPP. The scenario consisted of three tasks (1) install and camouflage a radio teletypewriter station; (2) communications; (3) relocation of the station. Environment: Temperature range from 7.1° to 29.1°C. Duration: Three days. One day in BDU and two days in MOPP 4. Subjects: Eight teams of five members each from communication companies, from the first and second Marine Division. Training: Unknown Design: Comparison of time to perform tasks in BDU/MOPP 4. Statistical analysis used Mann-Whitney U Test.	Time to complete tasks.	Of the timed tasks 4 were significantly degraded during the first day of MOPP 4. These are: (1) Installation and camouflage of radio teletypewriter station: Install AN/MRC-138 Jeep radio-degradation factor 1.6; (2) Communication: type word lists-degradation factor 1.3; (3) Relocation: disassemble AT-1011 whip antenna-degradation factor 1.4; (4) Relocation: take down camouflage net over MEP-15 generator-degradation factor 1.3. Type word lists was still degraded (factor of 1.2) on the second day of MOPP 4. Other three tasks were not degraded. Erect camouflage net over the mobile electric power (MEP)-16 generator-degradation factor of 1.3 (second day) not first. Second day's performance in MOPP 4 were lower than BDU times for some tasks. Recommendations: Radio teletypewriter teams should emphasize training under chemical warfare conditions.	A stable baseline was not established for performance in BDU. Consequently the effects of learning to perform the task are compounded with the effects of training in MOPP 4.	Stack and Sager (1988).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
7a. Field Trial (Armor) Phase IA	MOPP 4 and CVC helmet	Agent: None Scenario: Work-rest cycle of 2 hours in MOPP 4 and 1 hour in cool environment without MOPP 4. Work tasks were target engagement, decode message, identify vehicles and written psychological tests. Environment: Moderate Thermal environment. Duration: 24 hours Subjects: Two three-person crews Training: Unknown Design: Test endurance	Accuracy data recorded via video cameras for gunnery tasks; target engagement times; endurance times; speed and accuracy to process information. Observers.	Accuracy not affected; target engagement times increased throughout the test (linear); accurate information processing throughout test, significant decrement in speed after 7 hours; one crew completed the 24-hour period. Second crew terminated after 13.88 hours.		Ellis, Elliot, Johnson, Pimental, Rauch, and Smith (1986).
Phase IB	Same as IA	Scenario: Same as IA except rest period was eliminated and an ammunition loading exercise (63 rounds) added (all other conditions same as IA)	Same as IA	Target engagement same as IA, neither crew lasted longer than 9 hours due to loader (7 hours and 9 hours respectively); accuracy on psychological tests maintained, speed decreased, significant difference after 24 hours.		Same as IA

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
7a. Continued. Phase II	MOPP 4, Mask only	Agent: None Scenario: Baseline Testing: Stationary M1 and M60A3 Tank. Compare performance in stationary M60A3 and M1 tank systems with hatches closed. Loading task increased, i.e., full basic load of ammunition (63 rounds for M60A3, 55 rounds for M1). Environment: Full solar load. WBGT 16-25°C (60-76°F) Subjects: Four 4-person crews, all other conditions same as IA and IB. Design: ANOVA performed on crew target engagement times.	Same as Phase IA	Target engagement times increased throughout the test (performance deteriorated). Function was linear. Significant difference between two tank systems in terms of target engagement times (P<.005). A comparison between tank systems of crew member endurance indicated that crew members had a significantly larger endurance time in the M60A3 (P<.02). The mean operational loss times, i.e., the time the tank systems were judged to be ineffective were 10.09 hours for the M60A3 and 6.41 for the M1. During Phase II no M1 or M60A3 crew (either MOPP 4 or mask only) was able to complete 11 hours of the 24 hour scenario. Rectal temperatures and heart rates were slightly higher under MOPP 4 than mask only. The psychological tests showed a deterioration related to operational time for three of the six tests for the MOPP 4 and the mask conditions.	Small population size for statistical analysis.	Same as IA
Phase III	MOPP 4, Mask only (M60A3); MOPP 4 vs. BDU in M1E1 with over-pressure and micro-climate vests.	Agent: None Scenario: Tank platoon with tactical scenario. M60A3 task with hatches closed (MOPP 4 mask only); M1 hatches closed (MOPP 4); M1E1 with hatches closed, overpressure on and microclimate vest (MOPP 4 or BDU). Opposing force platoon of five M551 Sheridan tanks. Environment: Duration: 72 hours Subjects: Twelve 4-person crews (two M60A3, One M1, One M1E1) Training: 1 week Design:	MILES and to measure effectiveness of tactics and gunnery. Performance data collected through the sight as in Phase IA and following	The average endurance times of the M1E1 (16.48 hours) is significantly greater than the average M60A3 times (7.25);(P<.01) and the M1 times (6.95); (P<.01). The M60A3, M1 and M1E1 crews lasted an average of 7.83, 7.81 and 16.94 hours respectively. The MILES average kill ratio for the M1E1 was four times better during night defense and two times better during day defense than tanks in MOPP 4. Of 88 combat mission tasks: (1) for 18 tasks the criterion was not met (20.45%); (2) for 44 tasks the criterion was partially met (50%) and (3)for 26 tasks the criterion was fully met (29.54%). Failure on 11 of 18 tasks was related to wearing CW-protective combat clothing		Same as IA

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
7b. Field Trial (ARMOR) Phase IV (IRONMAN)	MOPP 4	Agent: None Scenario: Performance and endurance of crews wearing MOPP 4 with minimal heat stress during tactical scenario under five test conditions: (1) Baseline, inventory CW-protective combat clothing equipment and M1 hardware, current training and doctrine; (2) Training/Doctrine, modified procedures; (3) Hardware, different protective mask and newly developed equipment; (4) Combined, training/doctrine and hardware combined; (5) Modified Combined, same as combined except XM42 mask worn, music, commercial beverage and crew rotation. Environment: Dry bulb temperature range 21.7-24.6°C (71.1-76.3°F) Duration: 72 hours	Target engagement, target tracking, message encoding and decoding, driver skill test, ammunition re-supply, weapon disassembly and assembly, vehicle/aircraft identification, psychological measurement, core temperature and heart rate.	No crew member out of 48 completed the trial (core temperature indicated heat stress was not a factor). Stay time for crew members ranged between 3-32 hours, mean stay time of 14.5 hours (63% withdrew between 8-13 hours). The material and procedural variables had no measurable effect on crew performance or endurance. Glumm (1988, p. 4) concluded that tank crews dressed in MOPP 4 performing in temperate climatic conditions "will have difficulties sustaining effective operations in M1 tank system under NBC conditions for extended periods of time." Psychological results indicated that crew members who withdrew reported more intense symptoms than those who did not voluntarily withdraw. Symptom intensity increased during the test: thermal symptoms, 600% increase; respiratory, musculoskeletal, neurological, and gastrointestinal, 300-500% increase; fatigue, 200% increase. General deterioration of mood. Intensity of sleepiness, dizziness and unhappiness increased while aggressiveness, friendliness and clear thinking decreased.	No statistical analysis of the effects of the test conditions on crew performance and endurance was possible due to small sample size and confounding of many variables.	Glumm, (1988). Munro, Rauch, Banderet, Lussier, Tharion and Shukitt (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
8. Field Trial (Mechanized Infantry Personnel) Phase IA	MOPP 1 and MOPP 4	Agent: None Scenario: Four Bradley Infantry Fighting Vehicles (BIFV). For each 24-hour period, a 6-hour combat scenario of driving a test course (3.9 miles) with fixed stations for combat related tasks was repeated 3 times. Decontamination, a meal and removal of MOPP 4 was accomplished after each scenario. The fourth 6-hour period was for sleep. Environment: Test day temperatures relatively mild Duration: 72 hours (test was conducted over a 2 week period) Subjects: Four BIFV each with a 3-person vehicle team and 6-person dismount team (36 subjects).	Endurance.	Five casualties, three dismount and two vehicle team members (one for high rectal temperature who later returned). Fifty-nine hours of the 72-hour test were completed. Casualties occurred between 13-48.4 hours. Performance between MOPP 1 and 4 indicated no difference for 80 percent of the 106 tasks. For 18%, MOPP 4 had a longer time.	Report fails to discuss the implications of the number of casualties in Phase IB during mild to moderate climate conditions. Termination data for both Phase IA and IB were found only in the abstract.	Mitchell, Knox, and Wehrly (1987), Headley, Brecht-Clark, Feng, and Whittenberg (1988b).
Phase IB	MOPP 4	Training: Conducted on three days. Acclimation to MOPP 4 and training was a total of 23 hours. Design: Scenario: Two BIFV and one M113A1 operated continuous endurance runs without decontamination, meals or sleep. Subjects: 26 All other conditions of observations same as IA.	Endurance	The BIFU crews remained in the test for 31.4 and 33.3 hours. The M113 crew remained in the test for 37.9 hours. There were 11 casualties out of 26 subjects, none due to high rectal temperature. Nine casualties were members of the dismount team and two were members of the vehicle team. The casualties occured between 8 and 31.5 hours (mean 18.9 hours; median 14 hours).		

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measure	Findings and Recommendations	Critical Comments	Study
9a. Field Trial (Armor)	Phase 0, BDU Phase I & II, MOPP 4 Phase III, Micro-climate cooling M60A3 and overpressure in M1A1.	Agent: None Scenario: Test course (0.9 miles) with stations for medical instrumentation, psychological testing, ammunition supply (upload and download), refuel, security. Four tanks to set up and defend ridge line. Opposing forces attempted to approach hill without being detected or killed. Simulated artillery explosives added realism. Three phases (two iterations each). Phase 0. BDU (11 hours) Phase I. Baseline (MOPP 4). Phase II. MOPP 4 with materiel and procedure changes (from Glumm, 1986). Phase III. Microclimate cooling in M60A3 and overpressure in M1A1. Environment: Hot--near 29° C. Duration: 48 hours for each Phase. Conducted over two weeks. Subjects: 27 subjects. Training: Fully acclimatized to MOPP 4 (6 hours). Design: Repeated measures design.	Endurance, rectal temperature, performance measures.	None of the tank crews completed the 48-hour operation. The average crew endurance was 6 hours. One crew performed for 16.41 hours with cooling; one crew without cooling wearing MOPP 4 lasted 15.01 hours. Seven crew members passed out or were casualties due to high core temperatures. Twenty-six additional crew members elected to leave. No major difference between MOPP 4 (Phase I) and MOPP 4 with materiel and procedures or microclimate cooling and overpressure (Phase II and III).	No statistical analyses were performed due to the small number of subjects and the number of conditions tested. No appropriate experimental design.	Knox, Simmons, Christiansen, and Siering (1987); Headley, Brecht-Clark, Feng, and Whittenberg (1988b).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
9b. Field Trial (Armor)	BDU/ MOPP 4	Agent: None Scenario: Standard armor field test: Comparing BDU, MOPP 4, MOPP 4 with eating and coping strategies (FDX) Environment: Duration: Subjects: Twenty-seven males (6 four-person crews and 1 three-person crew). Training: Design: Psychological Test Battery administered Pre-Test, Post-Test and at 6-hour intervals. Designated casualties (withdrew or removed) and survivors (those remaining).	Psychological Test Battery: ESQ, Clyde Mood Scale (CMS), State Anxiety Questionnaire, Crew Atmosphere Questionnaire.	For MOPP 4, casualties had greater depressive tendencies and lower self-motivation than survivors, and casualties had more intense feelings of sleepiness or dizziness, compared to survivors on CMS.		Tharion, Rauch, Munro, Lassier, Banderet and Shukitt (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
10. Field Trial (Artillery)	Army battle dress uniform (BDU) and MOPP 4	Agent: None. Scenario: Comparison of BDU with MOPP 4 for sustained 24h artillery operation. Environment: Hot--94°-103° F average temperature for the MOPP 4 groups. The highest ambient temperature for the BDU group was 85.1° F (29.5° C). Duration: 24 hours. Subjects: Total of 36 subjects: nine subjects each for four 155-mm howitzer sections. Training: MOPP 4 groups had a total of 3 hours of MOPP 4 habituation while performing minimum to moderate activity. All crews were trained on tasks appropriate to the scenario. Design: ANOVA repeated measures. One BDU group; three MOPP 4 groups. Post hoc analysis between casualties and survivors.	Duration of mission, number of fire missions, number of rounds, psychological tests and rating scales, physiological variables of rectal temperature, heart rate.	Results BDU group completed 24-hr test; none of three MOPP 4 groups completed test. None of the BDU group failed to complete the test. Endurance ranged from 1 hr 53 min to 3hr 45 min, for the three MOPP 4 groups. Differences between casualties and survivors on intensity of symptoms and mood scales. Recommendations Additional training while wearing MOPP 4. Develop cognitive interventions to enhance endurance in MOPP 4. Develop psychological screening instrument to predict potential casualties.	a. Failed to analyze pre-test difference between casualties and survivors (to predict potential casualties). b. Ambient temperatures for the three MOPP 4 groups were significantly higher than for the BDU group.	Rauch, Banderet, Tharion, Munro, Lussier, and Shukitt (1986); Headley, Brecht-Clark and Whittenberg, (1988a). Knox, Mitchell, Edwards, and Sanders (1989); Headley, Brecht-Clark, Feng. Whittenberg (1988b).

Type of Study	Type of Protective Equipment/ Clothing	Conditions and Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
11. Field Experiments (XM-1 Tank with Auxiliary Cooling)	MOPP 4 compared to MOPP 1 and MOPP 3 and to MOPP 4 with auxiliary cooling	Agent: N/A Scenario: Day 1, MOPP 1, hatch open Day 2, MOPP 3, hatch open Day 3, MOPP 4, hatch open Day 4, MOPP 4, hatch open Day 5, MOPP 4, hatch closed, auxiliary cooling Day 6, MOPP 4, hatch closed Moderate work level Environment: 35°C, 25% rh. Duration: 6-day test (3hr/day). Subjects: Two tank crews, US Marines. Fit, extremely well trained tank crew, heat acclimatized, extremely well motivated. Training: Unknown Design: Comparison of ability to complete scenario under experimental conditions.	Rectal temperature (tre), skin temperature (ts), heart rate. Criterion for heat casualties: Heart rate of 180 beats per min, core temp. 39.5°C, ts converging to tre. Subjective evaluation by crew of ability to perform.	MOPP 3, hatch open—completed scenario. MOPP 4, hatch closed—terminated after 80 min; ability to perform estimated between 20-75%, errors within 30 min. MOPP 4, hatch closed, auxiliary cooling—completed scenario; ability to perform between 60-100%. Auxiliary cooling using a water-cooled vest alleviated heat stress. Combat vehicle crewman dressed in CW-protective clothing unable to perform fight fire mission when WBGT 32-35°C.		Goldman (1981) Toner, White, and Goldman (1981)

Type of Study	Type of Protective Equipment/ Clothing	Conditions and Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
12. Field Trial (Vehicle, M113/No Vehicle Pre-Assault)	U.S. MOPP 4: M17A1 protective mask, M6A2 chemical hood, protective coat and trousers (medium), boots, gloves (butyl) rubber with cotton liners. UK CB Protective suit, coat and trousers with attached hood, gloves, footwear (US). Control: Basic US Army clothing (BDU) with assault gear.	Agent: None Scenario: 1500 meter closed course, two 200-m assault segments comparison of U.S. and UK MOPP 4 chemical defense ensembles. Pre-assault: (a) No vehicle condition—sit in sun 1 hour; (b) vehicle M113 personnel carrier with hatch closed for 1 hour. Basic assault. Environment: Tropical environment (Panama CZ). Duration: Four days; 1 training day, 3 experimental days. Subjects: Ten US Army enlisted (five male and five female) from 193rd Infantry Brigade, Ft. Clayton, Panama. Acclimatized to tropical environment. Training: Unknown Design: Repeated measures, male/female groups, combat uniform (control), US and UK CB ensembles, pre-assault conditions.	Time to complete assault course; rectal temperature.	Unable to use times as dependent measures. US MOPP 4: For the vehicle pre-assault, three of five males had rectal temperatures which exceeded 102° and were removed prior to assault. One female passed out (apparently due to excessive respirator moisture). For the no-vehicle pre-assault, four of five males completed the assault; one removed due to excessive rectal temp. UK CB: Two males and one female completed vehicle pre-assault and subsequent assault. Significant differences between male and female core temperatures (female lower); less heat stress with UK ensemble compared with US. Enclosed M113 personnel carrier produced most severe heat stress. Recommendations: Need more information on effects of perspiration/fluids on M17A1 protective mask filters.	Repeated measures design completely compromised. No statistical comparisons among US, UK, and BDU conditions. Unable to evaluate amount of workload produced by assault since no times were given. Limited number in groups.	Hanlon, Jones, and Merkey (1982)

Type of Study	Type of Protective Equipment/ Clothing	Conditions and Observations	Type of Measures	Findings and Recommendations	Critical Comments	Study
13. Field Trial (Sustained Aviation Operations)	MOPP 1/ MOPP 4 Microclimate vests worn for 16/36 mission profiles.	Agent: None Scenario: Four flight missions of 90 minutes each which included low level operations, nap-of-the-earth flight, confined area operations, instrument approaches and other tactical operations. Flights performed with and without cooling vests. Environment: Hot-cockpit WBGT averaged between 24.5° and 30.6°C for the subjects; the maximum ranged from 29.4°-37.8°C. Duration: Six consecutive days; 12 hours in MOPP 4, 12 hours in MOPP 1. Subjects: Six aviators Training: Unknown Design: t-test on aircraft control, with and without cooling vest. t-tests performed on safety pilot ratings, with and without cooling vests.	Heading, airspeed, altitude. Safety pilot ratings and mission completion.	For 12 of 20 mission profiles flown without cooling vests, the mission was terminated due to medical problems (60%). Overall ratings and comments from safety pilots indicated that all subjects could fly safely in MOPP 4 and generally perform to Army standards.	Small experimental group permitted only summary statistical analysis. Use of t-test with six subjects is questionable	Mitchell, Knox, Edwards, Schrimsher, Siering, Stone, and Taylor (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
14. Field Trial (Helicopter)	MOPP 4, UK Chemical Defense Ensemble, and Standard Flight Suit	Agent: None Scenario: Three flights (one in each clothing condition). Each flight consisted of a precision flight profile (heading, altitude, airspeed and time) lateral hover, and 50-foot hover (1-hour period). Land, water/ad lib. Repeat iteration. Land, refuel aircraft 15-20 minutes. Repeat above until 4 hours elapse. Environment: Duration: Four 1-hour flights for 3 days. Subjects: Six Army aviators. Training: None Design: Two-factor ANOVA , repeated measures design for recorded data. Randomized block ANOVA for psychological tasks.	In-flight data recording psychological tests. Walter Reed Performance Assessment Battery: Encode/Decode/ Target Recognition, Logical Reasoning, Serial Math, and Reaction Time.	Automated data available for only 4 of 6 subjects. Only 1 of 4 subjects completed the six iterations in MOPP 4; 3 of 4 subjects completed six iterations in UK CW-ensemble; 4 of 4 subjects completed the six iterations in standard flight suit. The median SD heading error was the only significant variable for the recorded data. None of the subtests of the Performance Assessment Battery was significant.	Small number of subjects limited the power of the test.	Hamilton, Folds, and Simmons (1982); Hamilton, Simmons, and Kimball (1982).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
15. Field Trial (Aircraft Ground Crews)	MOPP 4; M17A1 Mask, Butyl rubber gloves and booties; MOPP 4 plus leather gloves.	Agent: None Scenario: Two ground crews performing quick turns in F-4. Environment: Duration: Subjects: Two ground crews. Training: Design: Compare 3 combinations of CW-protective combat clothing.	Proficiency Loss	Proficiency loss on 9 quick turn tasks for MOPP 4 ranged from 23%-51%; for M17A1 mask, butyl rubber gloves and booties ranged from 5%-44%; for MOPP 4 plus leather gloves ranged from 17%-51%.		Hinch (1982).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
16 a. Field Trial (Aircraft Maintenance Operations) Phase II	Fatigues and MOPP 4 (MCU-2/P mask and 7- or 14-mil gloves).	Agent: None Scenario: Comparison of maintenance technicians' performance on 26 tasks, twice in fatigues, and twice in MOPP 4. The first and last iteration was performed in fatigues. Environment: Hahn AB, FRG. Duration: October and November 1986. Subjects: Forty 4- and 7-skill level technicians. Training: Design: Collect data on performance, assess the impact of CW-protective combat clothing on performance, identify improvements to reduce performance decrement. Comparison of performance times.	Time to perform maintenance tasks, percent degradation, compromises in CW-ensemble; subjective task difficulty; assessment of component accessibility, visibility, mounting.	Findings: (1) Wearing the CW ensemble increased the time required to perform maintenance tasks; (2) The average percent time degradation due to CW-protective combat clothing was 30.7%; (3) The gloves were compromised during 15 tasks; the suit during 5 tasks. For 19 of 26 tasks, the CW ensemble was compromised; (4) Seven of 26 tasks were identified as the most difficult to perform in CW-protective combat clothing. Recommendations: (1) Training to handle sharp objects while wearing CW gloves; (2) Improved training on wear and care of CW ensemble; (3) Increased use of CW ensemble in operational situations such as phase inspections; (4) Use training aircraft for practicing tasks in CW ensemble; (5) include maintenance tasks in CW exercises.		Shipton, Beilstein, Chenzoff, Pitzer, Joyce (1988).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
16b. Field Trial (Aircraft Maintenance Operations) Phase III	MOPP 4 (MCU-2/P masks and 7- or 14-mil gloves).	Agent: None Scenario: Maintenance technicians' performance on 10 F-16 maintenance tasks performed six times (task 1 only performed 4 times) in MOPP 4. Four tasks were performed by a team of 2 technicians. Environment: Hahn AFB, FRG, 12° to 29° C (53° to 84° F). Duration: June and July 1987. Subjects: Fourteen subjects with 3 months to 5 years 2 months experience on the F-16 aircraft. Training: Before last two trials 5 received training handouts concerning how to work safely in the chemical ensemble. Design: Collect data on effect of MOPP 4 on performance, assess the effect of practice and interventions.	Time to perform maintenance tasks, number of compromises in CW ensemble.	Findings: When the time to complete the tasks on the first trial was compared to the time for the last trial, the average time for task completion was reduced on the average 52% (range 38-64%).		Shipton, Chenzoff, Joyce, Deibel, Weimer (1988).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
17a. Field Trial (Medical Unit Training Exercise)	MOPP 4	Agent: None Scenario: Questionnaires following unit training exercise in MOPP 4. Environment: Duration: One to two hours. Subjects: 105 members of the 352nd Evacuation Hospital. Training: 48% of subjects had not worn MOPP 4 previously; another 23% had only worn MOPP 4 once. Design: Assess the number of subjects reporting biopsychological symptoms.	Percentage of subjects reporting biopsychological symptoms.	Findings: Most frequent symptoms: a. Rapid breathing (n = 33, 48%) b. Shortness of breath (n = 33, 48%) c. Loss of side vision (n = 33, 48%) d. Anxiety (n = 20, 29%) e. Claustrophobia (n = 20, 29%) f. Visual disturbance (n = 20, 29%) g. Sweating (n = 29, 36%). Recommendations: Provide appropriate training in the use of MOPP 4 equipment.		Carter and Commer-meyer (1985a)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
17b. Field Trial (Medical Unit Training Exercise)	MOPP 4	Agent: None Scenario: Case study of five heat stress casualties during simulated CW field training exercise (FTX). Environment: Duration: 3 days. Subjects: 195 members of the 352nd Evacuation Hospital. Training: Design:	Frequency of biopsychological symptoms	1. Most frequent biopsychological symptoms: a. Excessive heat b. Rapid breathing c. Shortness of breath. 2. Personnel expecting or receiving chemical casualties under most stress. 3. Personnel less organized under conditions of simulated CW attack.		Carter and Cammer-meyer (1985b)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
17c. Field Trial (Medical Unit Training Exercise)	MOPP 4	Agent: None Scenario: Questionnaire following a simulated CW-medical FTX. Environment: Duration: 1 hour. Subjects: 182 military personnel. Training: Design: Assess the number of subjects reporting biopsychological symptoms; analyze casualties.	Frequency of biopsychological symptoms; analysis of casualties.	Findings: 1. Biopsychological responses: a. Feeling hot, 58% b. Shortness of breath, 68% c. Rapid breathing, 68% d. Visual problems, 56% 2. Some biopsychological responses reported by 85% of subjects. 3. Casualties assessment/19 subjects failed to complete FTX (11%) a. Shortness of breath (n = 13, 68%) b. Rapid breathing (n = 13, 68%) c. Feeling hot (n = 11, 58%) d. Visual problems (n = 9, 47%) Recommendations: Reserves be trained in CW-protective combat clothing for longer periods of time.		Carter and Cammermeyer (1989)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
18a. Field Trial (Shipboard Chemical Warfare Training Exercise) a. Questionnaire following CW-simulant attack.	Masks, UK Mark III Protective Suits, Impregnated Suits.	<u>Agent</u>: CW simulant delivered by air attacks. <u>Scenario</u>: Unalerted attacks on LST. Survey and decontamination team donned masks and suits. Questionnaire. <u>Environment</u>: <u>Duration</u>: Wore suit for 40 minutes. <u>Subjects</u>: 11 members of survey and decontamination teams. <u>Training</u>: 4 of 11 had no CW exercise experience. <u>Design</u>:	Responses to four sections of survey: 1) general, 2) mask, 3) suit, 4) job tasks.	<u>Results of Survey</u>: 1. General Section: a) adequate number of masks, suits and gloves but not boots. b) 8 of 10 were familiar with doctor kit. c) 5 of 10 were familiar with CW symptoms. 2. Mask Section: a) 7 of 11 reported visual problems. b) 5 of 11 reported fogging problems with mask. c) 5 of 11 reported communication problems caused by mask. 3. Suit Section: a) 6 of 7 reported exceedingly hot in suit. b) 4 of 7 reported suit degraded performance. 4. Job Task Section: a) CW equipment that degraded performance: Suit 2 of 7, mask 6 of 7, gloves 4 of 7, boots 1 of 7.		Garrison, Knudsen and Waskom (1982).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
18b. Field Trial (Shipboard Chemical Warfare Training Exercise) b. Combat Information in Center.	Masks compared to no masks.	Agent: None Scenario: Interaction between radarman and a chartman. Radarman observed positions and called them out. Positions charted by chartman. Environment: Combat Information Center. Duration: Training: Design: Comparisons of times to chart a position masked and unmasked.	Time to chart a position.	Results: 1. Time to chart a position was 2.6 minutes unmasked and 3.6 minutes masked. We calculated $D_T = -38\%$. 2. 0.4 positions had to be repeated unmasked and 3.5 positions had to be repeated for masked. We calculated $D_R = -77.5\%$ (8 fold increase in repeated messages).		Garrison, Knudsen and Waskom (1982).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observations	Type of Measure	Findings and Recommendations	Critical Comments	Study
19. Field Trial (Amphibious Shipboard CW Exercise)	BDU and MOPP 4	Agent: None Scenario: Determine effects of CW clothing on performance of shipboard tasks. Watch standing on LST and LPD during amphibious exercise. Compare BDU and MOPP 4. Environment: Between 65° and 76°F for all operations except causway where temperature was between 80° and 90°F. Sea condition was calm, visibility varied due to fog. Duration: Performance time of tasks ranged from 7-90 minutes. Subjects: Thirteen Navy enlisted males. Training: None. All trained in respective ratings. Experience 2-36 months. Design: Comparison of task performance in BDU and MOPP 4. Observe performance at least once in BDU and MOPP 4 for nine of thirteen subjects; observe performance in MOPP 4 only for four subjects.	Observation by SMES. Time to perform task 5. Questionnaire.	Findings: All amphibious operations observed were completed successfully during test. Most observations by SMEs of problems during MOPP 4 were communication problems. Communications were: distorted (10 observations), unsuccessful (4 observations), repeated (3 observations), and hand signals had to be used (2 observations). Ninteen negative comments of communication problems in MOPP 4 compared to 4 in BDU. Items of CW clothing which received negative comments were: Masks (12 observations), two-piece overgarment (11 observations), helmet (10 observations), gloves (8 observations), and boots (4 observations). Performance times were collected but variability unrelated to the CW clothing prevented analysis. Questionnaire: No communication problems reported when wearing BDU (N-12); 12 of 12 reported communication problems on first MOPP 4 trial. Visibility problems for 13/15 for MOPP 4 but none in BDU (N-9). Subjects indicated that training to perform task in MOPP 4 would improve talk performance (10/11) Ss. Recommendation: Subjects recommended increased training on mission-relevant tasks in MOPP 4. Authors report that communication problems are amenable to training. Use hand signals instead of verbal communications.	Time data unusable due to uncontrolled conditions. No attempt to reach stable performance level in BDU before performing tasks in MOPP 4. Effects of learning to perform tasks contaminated decrement data.	Carson, Moskal, and White (1989).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
20. Field Test (DT II of XM30 Protective Mask)	M17A1 and XM30 Protective Mask	<u>Agent</u>: None <u>Scenario</u>: Comparison of no mask, M17A1 and XM30. <u>Environment</u>: <u>Duration</u>: <u>Subjects</u>: 12 soldiers on Mobility/ Portability and Obstacle Course; 23 soldiers wore mask overnight; 11 unskilled marksman subjects. <u>Training</u>: <u>Design</u>: ANOVA(3-way), no mask, M17A1 and XM30.	a. Mean performance times; mobility/ portability and obstacle course. b. Drinking time c. Interviews d. Hits (rifle fire)	a. No differences on mobility/portability and obstacle course. b. Drinking time for XM30 significantly less when compared to M17A1. c. Seven of 23 soldiers removed mask at night; interviews indicated that they did not remember taking off masks. d. No differences in rifle firing.		Barnes, Hanlon, Harrah, Merkey (1983)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
21. Field Trial (XM40 Protective Mask and Rifle Firing)	M17A1, and three XM40 masks	<u>Agent</u>: None <u>Scenario</u>: Compared prototype masks to the M17A1 and no-mask condition. <u>Environment</u>: <u>Duration</u>: Wore mask for about 15 minutes for each trial. Total duration 1 1/2 days. <u>Subjects</u>: Ten soldiers. <u>Training</u>: 200 rounds of ammunition. <u>Design</u>: ANOVA–Tukey's Multiple Comparison Analysis.	Hit percentage (rifle fire) and reaction time. Questionnaires	1. <u>Findings</u> a. Significant main effects for masks and targets for hit percentage and reaction time. Contrasts indicated the significance was due to better performance of no-mask compared to mask conditions. Performance with XM40-1 was best. All prototypes were better than the M17 conditions. Target main effect due to better performance at 75M compared to 100M, and better performance of center target compared to left and right. b. We calculated D_A for no mask and 3 prototype masks. The results indicated a –22% to –25% reduction in hit accuracy decrement for the three prototype masks–D_A for M17A1 was –27%. c. The questionnaire results indicated that all subjects had to tilt their heads at an angle to obtain a sight picture. The XM40-1 tilt angle was less severe than the other three masks. No differences were found when ranking the masks. 2. <u>Recommendation</u>: XM40-1 should be considered first for use by infantry soldiers.	Small number of S_s (7 final).	Merkey and Harrah (1986)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
22. Field Trial (Cockpit Compatibility of XM-43 Protective Mask)	XM-43 Mask	Agent: None Scenario: Evaluate crew performance during operational missions flown in the 0H-58 and the UH-60 helicopters in areas of aircraft control, communications, field binocular compatibility, night vision goggles, extended wear with SPH-U helmet, and Aviation Life Support Equipment. Environment: Duration: Subjects: Training: Design:	Instructor Pilot Ratings	a. No performance degradation sufficient to abort mission.		Foster, Adams, Williamson, and Nowicki (1986)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
23. Laboratory Study (Fire Direction Center Tasks, Males)	BDU and MOPP 4	Agent: None Scenario: Comparison of BDU with MOPP 4 Control and MOPP 4 Heat Stress while performing fire direction center tasks. Environment: BDU at 21.1°C, 35% rh; MOPP 4 control, 12.8°C, 35% rh; MOPP 4 Heat Stress, 32.8° C, 61% rh. Duration: Four days, 7hr/day. Subjects: Twenty-three male soldier volunteers, ages 19-27 (median = 21). Training: Two weeks on task of Fire Direction Center (FDC), forward observers and army communicator personnel (first accuracy then speed of performance). Training on all tasks for 8hr in MOPP 4, spread over 5 days. Design: ANOVAs for each task using total error scores. Main effects experimental conditions, elapsed hours, interact on Design (control). Least Significant Difference Test between elapsed hours of work within conditions and between conditions for four elapsed hours of work (1, 3, 5, 7).	Errors for four tasks: (1) Computation of correction for artillery round (SITE). (2) Receiving and decoding pre-recorded, coded map grid coordinates (CODEWHEEL). (3) Receiving and decoding pre-recorded coded messages (CODEBOOK). (4) Plotting targets (grid coordinates) with deflection reference parts (MAP PLOTTING). First three experimenter paced, fourth subject paced.	Results: ANOVAs for computation of SITE, CODEWHEEL, CODEBOOK, and MAP PLOTTING for experimental conditions were significant ($p < 0.0001$), the decrements were 17%-23%; significant differences were found for hours of work for computation of SITE ($p < .05$), significant interactions (conditions by hours) were found for computation of SITE ($p < 0.002$), CODEWHEEL and CODEBOOK ($p < 0.0001$). The MOPP-Heat Stress condition for CODEBOOK, CODEWHEEL, and SITE was significantly different from both BDU control conditions for hours 5 and 7 but no difference was found for these tasks for hours 1 and 3. MOPP-CONTROL was different from BDU 1 and 2 and from MOPP-HEAT STRESS for several tasks at hours 1, 3 and 5 but not 7. The great majority of total errors were omission errors. Recommendations: (1) Establish a central office concerned with performance decrements due to wearing CW-combat protective clothing. (2) Intensive training and extensive experience on jobs in MOPP 4. (3) Document problems in training MOPP 4. (4) Document effect of CW-protective clothing on specific MOS's. (5) Central office conduct an overall assessment of effects of CW-protective combat clothing.	Order effects in data are likely. Performance of BDU-2 better than BDU-1 on number of targets plotted; MOPP Heat Stress condition resulted in less errors than MOPP control for CODEWHEEL and CODEBOOK for hours 1 and 3. Experimental design was inadequate in testing order effects.	Fine and Kobrick (1987, 1985)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
24. Laboratory Study (Fire Direction Center Tasks, Females)	BDU and MOPP 4	Same as Fine and Kobrick (1987, 1985) except subjects. <u>Subjects</u>: Eighteen female soldier volunteers ages 20-34 (median = 22).	Same as Fine and Kobrick (1987, 1985).	<u>Results</u>: Ten of 17 subjects terminated study prior to completion of 7-hour duration during MOPP-Heat stress condition. Remaining subjects showed no deterioration on any task. MOPP-Heat Stress was significantly different from the two BDU control conditions on all tasks for hour 5 and 7 due to the large number of terminations. MOPP-Control was significantly different from BDU control for all hours for CODEBOOK and number of targets plotted, and for hours 1 and 3 for the CODWEHEEL task. <u>Recommendation</u>: Train under the most realistic conditions possible in MOPP 4.	Design did not permit analysis of order effects.	Fine (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
25. Laboratory Study (Speech Intelligibility)	BDU and MOPP 4	Agent: None. Scenario: Testing to determine the effects of mask and hood and to compare Army BDU and MOPP 4 under various levels of ambient temperatures and clothing conditions. Environment: Same as Fine and Kobrick (1987, 1985). Study done in conjunction with this study. Duration: Four days, 7hr/day. Subjects: Twenty-three male soldiers ages 18-35. Training: One week. Practice with 300 words, 50 of which are test words on Modified Rhyme Test. Six tests conducted in bare-headed condition. Design: Two-way ANOVA (Treatment × Hour) N = 21, on Modified Rhyme Test scores (hours 2, 4, 6).	1. Audiometric Test 2. Percent correct words.	Results: a. Audiometric Data: Mask has a significant effect at the following frequencies: 500 Hz; 4000 Hz; and 6000 Hz. b. Speech intelligibility data. MOPP IV--Heat stress significantly reduced speech intelligibility over BDU control days; MOPP control not different from BDU control. Mean scores lower during 6h than 2h or 4h. Performance of 6h for MOPP-heat stress significantly different than all other data points.		Johnson and Sleeper (1985).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
25. Laboratory Study (CW-Masks on SPH-4 Aviator Helmet)	M-24, XM-33 and UK AR-5 masks.	Agent: None Scenario: Evaluate masks on speaker intelligibility, listener intelligibility, and attenuation. Environment: UH-60A noise environment. Duration: Subjects: Ten subjects. Training: Design: Percent phonetically balanced words.		1. XM33 very deficient in intelligibility. 2. M-24 improves intelligibility of SPH-4 helmet. 3. All CW-masks degrade speech intelligibility when a listener is wearing SPH-4. 4. M-24 and XM-33 with and without protective hood degrade the attenuation characteristics of the SPH-4 helmet.		Mozo and Peters (1984)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
27. Laboratory Study (XM-40 Mask on Attenuation and Speech Intelligibility of SPH-4 Helmet)	XM-40 Mask	Agent: None Scenario: Determine the effects of 3 prototypes versions of the XM-40 Mask on attenuation and speech intelligibility. One version was tested for attenuation of the SPH-4 helmet with and without the mask. Environment: Duration: Subjects: 10 college students. Design: t-tests comparing mask and no mask were computed for each frequency for attenuation. A repeated measures one-way analysis of variance was performed on the intelligibility scores.	Thresholds of audibility for attenuation. Percent correct scores of phonetically balanced words for speech intelligibility.	Findings: Significantly less attenuation was found for the mask condition for 2000, 6300, and 8000 Hertz. The XM-40 mask was found to significantly degrade the ability to understand speech compared to the SPH-4 helmet without the mask. The SPH-4 without a mask had higher mean speach intelligibility scores when compared to the helmet with three prototype masks. These differences were significant. Recommendations: Further efforts should be made to improve the mask compatibility with the SPH-4 helmets and careful attection should be given to microphone placement within the mask.	No ad hoc contrasts were made to determine the focus of the difference between experimental conditions. The authors concluded that the significant speech intelligibility was due to A and C compared to the SPH-4 but failed to test this with contrasts.	Nelson and Muzo (1985).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
28. Laboratory Study (Visual Perception)	BDU/ MOPP4	Agent: None Scenario: Comparison of BDU with MOPP 4 and MOPP 4 heat stress while detecting visual signals. Environment: MOPP 4 at 55°F (12.8°C), 35%rh; and MOPP 4 heat stress 91°F (32.8°C) 61%rh; BDU 70°F (21.1°C), 35%rh. Duration: Four days. Subjects: Twenty-four male subjects (16 completed the study). Training: Two weeks. Design: Two, three-way multi-variate analyses of variance for repeated measures; Rings x Day x Hour and Axis x Day x Hour.	Response times, computed arithmetic mean.	1. Significant main effects for peripheral location of stimulus rings, axis, days, hours not significant. 2. Major charge is signal detection due to MOPP 4 and MOPP 4 Heat Stress. 3. Mean RTs increased systematically with stimulus locations in the superior and inferior visual fields. 4. Arithmetic means for 4 days were computed; MOPP 4 and MOPP 4 heat stress had higher response times than the two control days.		Kobrick and Sleeper (1986)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
29. Laboratory Study (Manual Dexterity)	Butyl rubber gloves and M17A1 gas mask with hood.	Agent: None. Scenario: Comparison manual dexterity on two standardized tests under various conditions of gloves and gas mask and hood. Environment: N/A Duration: Five days. Subjects: Twenty-two male soldiers. Training: None. Design: Three-way ANOVA on two tests.	Time to complete the test.	Results: Wearing butyl rubber gloves produces significant performance decrement. Takes longer to reach asymptote wearing gloves. Mask and hood produced no decrement in manual dexterity. Training for 5 days improves performance while wearing gloves about 33%. Recommendations: Intensive training in job-specific tasks while wearing chemical protective clothing.	Failed to calculate the effects of training in chemical combat protective clothing.	Johnson and Sleeper (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
30. Laboratory Study (Tactility of CW Gloves When Performing Medical Tasks)	Fatigue uniform, MOPP 4, MOPP 4 with tactical glove.	<u>Agent</u>: None. <u>Scenario</u>: Performed nine basic medical tasks in three clothing conditions for 6 days. <u>Environment</u>: Air conditioned, indoor. <u>Duration</u>: Six days. <u>Subjects</u>: Nine subjects from 41st Combat Support Hospital. <u>Training</u>: <u>Design</u>: Repeated measures, analysis at variance.	1. Evaluation of performance of a task using tasks/ conditions/ standards. 2. Response time. 3. Errors.	<u>Results:</u> All subjects were able to perform all tasks in MOPP 4 and in MOPP with prototype glove. There was substantial improvement over time, for all conditions. Practice does not eliminate performance decrement in MOPP 4 or MOPP with prototype glove. Ss required 30.2% longer to perform tasks in MOPP with prototype glove and 55.2% longer in MOPP 4. Ss in fatigues performed 7 of 9 tasks faster than in MOPP with prototype glove and subjects with the prototype glove performed 7 of 9 tasks faster than in MOPP 4. <u>Recommendations:</u> Medical personnel should receive periodic intensive training in MOPP 4. Manning patterns under CW conditions should be studied. Adopt prototype glove for tasks requiring high levels of dexterity.	No base line in fatigues was established prior to the experiment.	King and Frelin (1984)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
31. Laboratory Study (Psychological Effects)	Flight suit and U.S. Aircrew CW Ensemble	Agent: None Scenario: Comparison of performance on psychological tests after wearing CW ensemble. Environment: WBGT temperature was 19.8°C at the beginning of the test period and 22.2°C at the end. Females experienced a greater temperature range than males (20.2°C-20.8°C for males, 19.4°C-23.5°C for females). Duration: Six hours. Subjects: Twelve males and 12 females. Training: None. Design: Two-factor ANOVA (Ensemble x Sex)	Test scores on four subtests of PAB. Change Scores (before and after wearing CW ensemble) computed.	Results: Lack of statistical reliability of the variable tested. Few performance measures across sex or ensemble were significant. There were large standard deviations for all tests. No conclusions were drawn from the tests.	Ambient WBFT temperatures for males and females (one of the factors) were different. Subjects were bored.	Hamilton and Zapata (1983)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
32a. Laboratory Study (Cognitive Problem Solving)	BDU, MOPP 2, MOPP 4	Agent: None. Scenario: Comparison of BDU, MOPP 2 and MOPP 4 using cognitive performance tests. Environment: Command Post Vehicle ≤ 75°F. Duration: Twenty-four hours continuous operations for each condition (total 3 days). Subjects: Six male soldiers. Training: Trained on cognitive tests for 1 week; 12 trials in vehicle during 3 clothing conditions. Design: 3 × 7 repeated measures, ANOVA for percent problems completed and percent wrong for each cognitive test. Schaffe comparisons. Main effects were MOPP level and time of day.	Percent problems completed and percent wrong for Math Computation, Pattern Recognition, and Number Comparison for seven time periods.	Results: Significant main effects for three cognitive tests for percent complete and for three cognitive tests, for time of day. Significant contrasts were between MOPP 4 and MOPP 2, and MOPP 4 and BDU. Accuracy not affected.	Small number of subjects.	Rauch, Witt, Banderet, Tauson, and Golden (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
32b. Laboratory Study (Cognitive Problem Solving)	CW Masks and Gloves	Agent: None. Scenario: Using a paper math test, comparison of effects of gloves, mask, mask and gloves, and no gloves and no mask. Environment: 72°F. Duration: Testing session was two minutes for each condition. Subjects: Eight females and seven males. Training: Each subject practiced twelve math problems in each of the four conditions prior to the test. Design: The experimental design was a 2 factor between subjects (SEX) by 4 factors within-subjects (Conditions) repeated measures analysis of variance design.	Number of problems completed and the number of problems wrong (2-min test).	There was a significant main effect for CW conditions on the number of problems completed but not on the number of problems wrong. There were no differences between male and female subjects for either the number of problems completed or the number of problems wrong. A least significant difference test resulted in a significant contrast between CW-mask and CW-gloves and no mask and no gloves (D_T=10%) and between CW-mask and no mask and no gloves (D_T=8%). The authors attribute the differences to limitations of manual dexterity and sensory-perceptual capabilities.		Rauch, and Tharion (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
33. Laboratory Study (Training for Donning Masks)	Masks	Agent: CS. Scenario: Comparison of effectiveness of naval recruit chemical defense training. Environment: Chamber. Duration: Subjects: 362 male and female recruits. Training: Test was part of chemical simulation training procedure. Recruits don masks, enter chamber with CS present, and remove masks. Design: Three phases of training. t-tests-- (1) Prior to training (2) After classroom CD training (3) After chamber exercise to demonstrate effectiveness of masks. Take-off mask in the presence of CS.	(1) Knowledge Test (2) Questionnaire on expectations.	(1) Knowledge scores increased as a result of classroom training. Remained stable for chamber experience. (2) Significant decline in performance expectations as a result of chamber exercise.		Driskell, Carson, and Moskal (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
34. Laboratory Study (Effects of Drug Antidote and Heat Stress)	BDU and MOPP 4	Agent: None. Scenario: Comparison of BDU and MOPP 4 Control, Drug, Heat Stress and Drug and heat stress. Environment: BDU: (1) Control at 70°F, RH 30%; (2) Drug at 70°F, RH 30%; (3) Heat Stress at 95°F, 60% RH; (4) Drug and Heat Stress at 95°F, 60% RH. MOPP 4: (1) Control at 55°F, 30% RH; (2) Drug at 55°F, 30% RH; (3) Heat Stress at 95°F, 60% RH; and (4) Drug and Heat Stress at 95°F, 60%RH. Duration: 4 conditions (4 test days) 3 repetitions of 2h each, a total of 6 hr/day. Subjects: BDU–15 Ss. MOPP 4–8 Ss. Training: Subjects trained on all tasks, 6 hr/day for 5 days. Design: Three-factor ANOVA repeated measures for each task. Drug x Heat x Cycles for 2 studies–(1) BDU, (2) MOPP 4 which used different subjects 4 test days: (1) Control (2) Drug only (3) Heat Stress only (4) Drug and Heat Stress combined.	The following tasks were used: (1) Visual acuity, (2) Phoria, (3) Stereopsis, (4) Contrast sensitivity, (5) Speech intelligibility, (6) Arm-hand steadiness, (7) Voluntary muscle tremor, (8) Gross manual dexterity, (9) Fine dexterity (one-handed), (10) Fine dexterity (two-handed, (11) Body mobility and coordination, (12) Simple visual reaction time, (13) Choice visual reaction time, (14) Rifle marksmanship, (15) Verbal reasoning, (16) Digit symbol substitution, (17) Eye hand coordination, (18) Tapping.	(a) BDU Study (1) Drug– (a) affected reaction time, (b) gross body mobility, and (c) rifle marksmanship, (d) overall rate of verbal reasoning, (e) acuity and phoria on some measures. Summary–slow down reactivity and reduce body coordination, vision. (2) Heat: (a) reduced steadiness, (b) less accurate marksmanship. (3) cycles: (a) speech intelligibility, (b) manual dexterity. (4) Subjective measures. (b) MOPP 4 Study (1) No subject completed the 2nd and 3rd cycle of the test for the heat stress and combined drug and heat stress conditions. The worst scores possible were assigned to all variables. All performance variables were significant for for heat stress. (2) The following drug performance measures were significant: rifle marksmanship (all 3 measures; pop-up ranges and 1 x 1 and 2 x 2 short group); simple and choice reaction time, body mobility, verbal reasoning, and digit symbol. All visual activity measures except binocular were significant only for vertical phoria.	Two separate experimental studies were reported: (1) BDU with 15 subjects; (2) MOPP 4 with 8 subjects; each of which was exposed to the same experimental conditions using multiple dependent measures (18 listed, some of which had more than one measure). It appears that a more economical design would have provided a clearer picture of the impact of the treatment effects, i.e., BDU vs. MOPP 4, HEAT vs. NO Heat Stress; Drug vs. NO drug; cycles; and Heat & Drug interaction. It is impossible to determine from the report, how the data were analyzed, or what error terms were used. The design is described as a 3-way ANOVA using a repeated measures design. In addition, the current design does not permit the effects of order to be analyzed. It would have been helpful to determine the correlations of the various dependent measures. The effects of heat stress when encapsulated in MOPP 4 are well known. The USARIEM has a computer model which predicts heat stress effects. It appears that the effects of the heat stress could have been predicted prior to the study. If this had been done the variables could have been adjusted to permit the study to be completed using an economical statistical design.	Kobrick, Johnson, and McMen-enny (1988; 1990a; 1990b).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
35. Laboratory Study (Rifle Marksmanship)	a. BDU, b. Fighting load (BDU plus helmet, webgear, and full canteen), c. MOPP 4	Agent: None. Scenario: Comparison of the effects on rifle marksmanship in a rifle fire simulator, on types of clothing conditions. Environment: Duration: Four days of practice and one test day. Subjects: 30 male soldiers matched on rifle marksmanship ability. Ten were assigned to each of the three clothing conditions. Training: For four training days, each subject fired a self-paced series of 9 shots until he had a tight shot group, then he received practice firing at 32 randomly presented pop-up targets under two conditions - rifle supported with sandbags and rifle unsupported. Design: The accuracy of firing data was analyzed using a 3x2 (clothing x rifle support) analysis of variance between subjects design; the shot group tightness was analyzed by means of a Krushal-Wallis one-way (clothing) analysis of variance by ranks.	Total number of targets hit, and the number of attempts before a tight shot group was attained.	The results of target pop-up marksmanship indicated a significant main effect for clothing and for rifle support. Newman-Keuls tests indicated that rifle marksmanship was significantly poorer for MOPP 4 than either the BDU ($D_A = -19.3\%$) or the fighting load ($D_A = -15.0\%$). Rifle marksmanship was significantly better when the rifle was supported by sandbags than when it was fired unsupported. No significant difference was found for the tightness of the shot group. The authors concluded that the extra bulk of MOPP 4, particularly the gas mask, produced the performance decrements. Wearing the gas masks requires that the rifle be tilted to align the rifle sights with the targets.		Johnson, Mc-Menemy, and Dauphinee (1990). Johnson (1991)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
36. Laboratory Study (Pilot Performance)	Flightsuit, MOPP 4 (Aircrew Uniform Integrated Battlefield and M43 Mask)	Agent: None. Scenario: Comparison of pilot performance using a simulated tactical flight profile while wearing a flight suit and MOPP 4. Environment: Dry bulb temperatures were T_1: 21.6°C, and 50%rh and T_2: 35.9°C, 50% rh Duration: Three flights of two hours/day for five days. 1st hour - low level navigation; 2nd hour - upper air maneuvers. Subjects: Sixteen Army aviators who were qualified in the UH-60. Training: A week of training on the flight profile. Training was first in the flight suit and then in MOPP 4. Design: Mon.: Baseline, flight suit, T_1. Tue.: Flight suit, T_2 Wed.: MOPP 4, T_1 Thur.: MOPP 4, T_2 *Fri.*: Flight suit, T_1 Analysis of variances was completed and Duncan's Multiple Range Test was used for Posteriori comparisons.	RMS error was computed for 69 different flight maneuvers/ parameters. Data were automatically recorded twice a second on a flight data recorder.	Duncan's Multiple Range Test contrasts indicated that the MOPP 4 hot condition had 19 out of 55 maneuver parameter data sets for which the RMS error was significantly greater than for at least one of the other three clothing/heat conditions. For the MOPP 4 mild and the flight suit, hot conditions, 4 RMS errors were greater when compared to the other three conditions. Finally for the baseline, 2 RMS errors were greater. The RMS error was greater for Automatic Flight Control System out for most but not all maneuver parameters which indicated that pilot performance further deteriorated under higher workload.	No analysis of variance results were reported but Duncan's multiple Range Test Contrasts were presented.	Thornton and Caldwell (1991)

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
37. Laboratory Study (Pursuit Tracking)	Protective Mask M17A2	Agent: None. Scenario: Comparison of mask/no mask pursuit tracking performance in a pursuit tracking simulator. Bright and dim light; vertical and horizontal tracking. Environment: N/A. Duration: Three test days--20 trials/ day;10 bright/10 dim. Subjects: Sixteen soldiers. Training: Two days in tracking simulator. Design: Between subjects, repeated measure ANOVA. Separate ANOVAs were performed for the bright and dim light for each of the three dependent measures to test the effects of mask/no mask and test days.	Raw scores, vertical and horizontal tracking, were used to determine Root Mean Square error (RMS); Time-On-Target, and Maximum absolute error.	Results: The Time-On-Target ANOVAs were significant for both the bright and the dim light conditions; the RMS error ANOVAs were significant for bright light, vertical axis and dim light horizontal axis. Only the maximum absolute error ANOVAs were significant for bright light vertical axis, bright light horizontal axis, bright light horizontal axis and dim light horizontal axis. The test days ANOVAs were not significant for any measure. The results suggest that soldiers using direct-view optics could experience severe difficulties when wearing the protective mask. Recommendations: The authors recommend training TOW and GLLD operators with the protective masks.	The lack of significance of days indicated that overall performance did not change over the course of the study, but several treatment x days interactions were significant. This indicates that changes in tracking strategies were taking place. An analysis of the effect of day for the mask group was needed.	Barba, Stamper, Pentar, and Molchany (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
38. Laboratory Studies (Tactical Computer)	BDU vs. MOPP 4	Agent: None. Scenario: Comparison of BDU with MOPP 4 while operating the Tactical Computer Terminal (TCT). Environment: N/A. Duration: 35-minute test period for one clothing condition, 15 minute break, 35-minute test period for the second condition. Subjects: Twelve soldiers. Training: 2 weeks new equipment course; no training in operating the TCT in MOPP 4. Design: Within subjects design--ANOVAs computed for each task.	Time to perform tasks and errors.	Subjects were able to perform all tasks under both clothing conditions. No significant differences for time to perform any tasks. Decrements due to MOPP 4 ranged from +12% to -36%. Modification in how a task was performed was observed. Narrow field of view was accommodated by subjects' frequent head movements.	Time of test was too brief to determine if the clothing conditions performance could be sustained over a significant period of time.	Lussier and Fallesen (1987).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
39 Laboratory Study (Scanning Time with XM40 Mask)	Protective Mask M17; XM40	Agent: None. Scenario: Comparison of mask and no-mask conditions to scan an area 58 degrees wide by 21 degrees high using M19 binoculars Environment: N/A. Duration: N/A Subjects: 14 soldiers. Training: Six trials with no mask. Design: ANOVA for time to scan.	1. Field-of-view 2. Scan Time 3. Stand Off Distance	Significant main effect masks (due to mask-no-mask). No difference in standoff distance. Field of view in no-mask condition was 6.6° and was reduced to 2.8°-3.1° for masks.	Failed to complete Latin Square design.	Harrah (1985).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
40. Laboratory Study (Missile Maintenance Performance)	BDU, BDU with mask and hood, BDU with glasses, and MOPP 4	Agent: None. Scenario: Easy and difficult maintenance tasks. Easy task with Tow self-test; difficult task was remove and replace motor-driven rotating mirror assembly in Dragon night sight tracker. Environment: Constant temperature isolated test stations. Duration: Subjects: 11 subjects (male) and were graduates of Tow/Dragon Program Advanced Individual Training (AIT) maintenance course. Training: AIT only Design: Separate ANOVAs for easy and difficult tasks with replications of each, and within subject conditions (4 clothing) X trials design was used. Duncan's Multiple Range Tests were performed.	Time to complete each task.	Results: A 3-way ANOVA (condition X trial X task) showed that all three main effects were significant and a condition X task interaction was also significant for the easy task. Two-way ANOVA indicated that trials were significant but not clothing conditions. For the hard task both conditions and trials were significant P = .001. For the easy tasks, the Duncan Multiple Range Test indicated that the first trial was significantly different from trials two and three. For the hard task, the Duncan Multiple Range Test indicated that MOPP 4 times were significantly shorter than the other three and BDU times were significantly shorter than the other three. The BDU with mask and hood and BDU with gloves were not significantly different from each other. For the hard task the first trial was significantly different from trial two and three.	Small number of subjects for the complex design. The description of the randomization of the presentations for conditions by tasks by subjects fails to indicate the specific analysis that was performed. It is clear, however, that performance changes over trials for both the easy and the hard task. Learning to perform the tasks was confounded with learning to perform while wearing different CW-protective combat clothing conditions.	Waugh and Kilduff (1984).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
41. Laboratory Study (Effect of CW gloves on digital terminal performance)	Three types of CW-gloves, i.e., 7-mil, 14-mil, and 25-mil butyl rubber, and masks were compared with no gloves and mask (baseline)	Agent: None. Scenario: Determine if wearing CW mask and various combinations of CW gloves (standard, 7 mil and 14 mil gloves) and cold weather gloves degrade performance on a tactical key type terminal. A static mode and a mobile mode were tested. Instructions were that accuracy was more important than time. Environment: Assume no environmental effects. Duration: Subjects: 31 subjects Training: 19 subjects had no previous experience with tactical field touch tone phone, 12 had two months to eight years experience (average 2.6 years). Design: 2 x 15 (Mode x Conditions) factorial having 31 observations per cell.	1. Character accuracy, i.e., correct digits - total digits 2. Message error rate, i.e., correct messages (7 digits) - total messages	Results: No significant difference in character and message accuracy between baseline and CW gloves (neither standard, 7 mil or 14 mil). No significant difference between conditions when operating in the static mode. Message accuracy rate and character accuracy rate degraded when cold weather glove is added to CW-glove conditions.		Peterson (1986).

Type of Study	Type of Protective Equipment/ Clothing	Conditions of Observation	Type of Measures	Findings and Recommendations	Critical Comments	Study
42. Questionnaire (Common Defense Skills)	N/A	Agent: None. Scenario: 37-item questionnaire assessing the status of chemical defense common skills knowledge. Environment: N/A. Duration: N/A. Subjects: 333 enlisted personnel aboard 16 ships. Training: N/A. Design: Descriptive statistics of percent correct for 11 major categories. Correlational analyses with biographical data.	Percent correct on knowledge items.	1. Poor state of training a. About 50% had received no shipboard exercise b. About 2/3 had worn protective clothing 0-60 minutes duration at any one time. c. Forty percent reported last training was recruit training which generally occurred 1 year prior. 2. Poor knowledge a. Mean correct score 12.6 items (34%). b. Donning and doffing procedures had the poorest score of 11 categories (9% of six items correct). None of the 333 subjects answered all six items correctly. c. 22.2% were able to answer all questions in one of the 11 categories correctly. 54.7% failed to answer one category correctly. 3. Recommendations: a. Expand curriculum of 2-day classes to include common skills; increase training throughout. b. Regularly conduct shipboard exercise in full protective gear. c. Distribute and evaluate instructor manual.	N/A	Moskal, Driskell, and Carson (1987).

APPENDIX D

MAINTENANCE TASKS

(Montgomery, 1987)

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MAINTENANCE TASKS

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TASK 1

"Remove and Replace M60A3 Power Pack," was performed by four-person crews, each of whom performed the task once in BDU and once in MOPP 4. Six of the crews first performed Task 1 in BDU and four in MOPP 4. One of the six crews failed to perform the task in MOPP 4 due to heat stress which left only nine crew comparisons. The mean time for the six groups that first performed Task 1 in BDU was 141 minutes or an average of 27 minutes less than the mean time, 168 minutes, for the four groups that first performed Task 1 in MOPP 4 (see Table 2). Examination of the mean time for the second trial indicates the same relationship, i.e., the mean time for the four groups that performed the task second in BDU was less (34 minutes average); for the second trial, the BDU mean time was 73.2 minutes, compared to the MOPP 4 mean time of 107.2 minutes.

In all cases except one, each group performed the task faster on the second trial regardless of whether BDU or MOPP 4 was worn on the first trial. It is not surprising to find that the time decreased on the second trial since none of the crew members had previous experience in performing the task with each other. Montgomery reported a 35 percent ± 20 degradation due to MOPP 4.

Montgomery (1987) did not compute difference scores between the first and second trials but the available raw data permitted the computation of such scores. We computed difference scores and algebraic means for the BDU first trial group (N of 5) and the MOPP 4 first trial group (N of 4). Table D-1 presents the raw data, the means and the standard deviations from Montgomery (1987) and also presents algebraic difference scores and algebraic percentage changes that we computed. The mean difference between the first and second trial for the group of teams which first performed Task 1 in BDU was 38.9 minutes compared to the mean difference of 95.2 minutes when the first trial was performed in MOPP 4. Next, percentage differences between the first and second trial were computed and averaged (algebraically) for the BDU first group and the MOPP 4 first group.

The MOPP 4 first group showed a 53 percent decrease in time to accomplish the task on the second trial (in BDU) while the BDU first group showed only a 27 percent decrease in the mean time to accomplish the task on the second trial (in MOPP 4).

Table D-1. Time (min) to Remove and Replace M60A3 Power Pack (Adapted from Montgomery, 1987)

	Trial							
	Battle Dress Uniform (BDU)		Mission-Oriented Protective Posture (MOPP 4)		Difference Scores		Percent Change	
Team	1	2	1	2	BDU First	MOPP 4 First	BDU First	MOPP 4 First
1a*	115.5	--**	--	126	+10.5	--	+9	--
2a	--	80	148	--	--	− 68	--	− 46
3a	230	--	--	142	− 88	--	− 38	--
4a	--	76	271	--	--	−195	--	−72
5a	165	--	--	100	− 65	--	− 65	--
1b	135.7	--	--	91.3	− 38.4	--	− 28	--
2b	109.6***	--	--	MD***	--	--	--	--
3b	--	80.8	140.4	--	--	−59.6	--	−42
4b	--	55.8	114.0	--	--	− 58.2	--	− 51
5b	89.9	--	--	76.5	− 13.4	--	−15	--
Total	736.1***	292.6	673.4	535.8	− 194.3	− 380.8	−137	−211
$\bar{X}$	147.2***	73.2	168.4	107.2	− 38.9	− 95.2	− 27.4	− 52.8
SD	50.5***	11.8	70.0	26.5	--	--	--	--
N	5	4	4	5	5	4	5	4

* a = trials in April, 1984; b = trials in July 1985.

** Dash indicates opposite uniform group provided data for this trial.

*** Missing Data for second trial. First trial data not included in the analysis (did not recompute SD).

The analyses support the following conclusions:

(1) Regardless of dress, all groups perform the task better on the second trial (with one exception).

(2) Performing in MOPP 4 increased the performance time as compared to BDU. The best estimate of the magnitude of the increase is the mean percentage difference between the MOPP 4 first group and the BDU first group--a difference of 25.4 percent. Montgomery estimated a 35% ± 20 degradation based on regionalized statistics (1987).

It cannot be determined from this task if repeated practice in MOPP 4 improves performance since no group performed the task in MOPP 4 more than once.

TASK 2

"Remove and Replace M60A3 Transmission" was performed by two-person crews; one member was experienced and the other was a student. Eight crews performed the task once in BDU and once in MOPP 4. The two remaining crews performed the task three times. One of these performed the task in the following order: first, MOPP 4; second, BDU; third, MOPP 4; the order of task performance for the others was MOPP 4, BDU, BDU.

Four crews first performed Task 2 in BDU; the mean time to perform the task was 125.7 minutes (see Table D-2). Six crews first performed Task 2, in MOPP 4; the mean time to perform the task was 157.8 minutes. One of these teams performed the task only in MOPP 4; their task performance time was 307 minutes--154 percent higher than the next lowest time. If this time is excluded from the data base, the mean times for the first tries are comparable across the two groups, i.e., 125.7 minutes for BDU first, and 120.7 for the MOPP 4 first.

The effect of MOPP 4 is clearly seen when the second trial data are examined. The mean time on the second trial for the BDU "second group" was 73.5 minutes; the mean time for the MOPP 4 "second group" was 125.9. It is clear from the means that those teams dressed in BDU for the second trial all reduced the time required to complete the task compared to the first trial, which was performed in MOPP 4. Only one of the four teams dressed in MOPP 4 for the second trial reduced the time and three teams required increased times. In order to quantify this effect we computed difference scores and percentage change from the raw data. The raw data, the means, and the standard deviations from Montgomery (1987) plus the algebraic difference scores and the percentage change scores are presented in Table D-2. For the MOPP 4 first group, the mean difference score on the second trial was −47.2 minutes, or a 36.1 percent reduction for the second trial in BDU. The BDU first group mean showed little change, +0.2 minutes (+2.7 percent), in the time

to complete the task on the second trial in MOPP 4. The percentage decrement associated with MOPP 4 can be calculated from the percentage change scores to be 38.8 percent. Montgomery (1987) calculated a 50 percent degradation resulting from MOPP 4 based on a regionalized statistical approach. The same conclusions drawn from the results of Task 1 can be drawn from the findings of Task 2.

Table D-2. Time (min) to Remove and Replace M60A3 Transmission (adapted from Montgomery, 1987)

Team	Trial						Difference Scores		Percent Change	
	Battle Dress Uniform (BDU)			Mission-Oriented Protective Posture (MOPP 4)						
	1	2	3	1	2	3	BDU First	MOPP 4 First	BDU First	MOPP 4 First
1a*	197	--**	--	--	173	--	- 24	--	-12	--
2a	--	94	--	200	--	--	--	106%	--	- 53
3a	127	--	--	--	141	--	+14	--	+11	--
4a	--	68.5	--	96	--	73	--	-27.5	--	-28
5a	--	97	--	139	--	--	--	-42	--	-30
1b	--	MD***	--	307***	--	--	--	--	--	--
2b	97.4	--	--	--	104.5	--	+7.1	--	+7.3	--
3b	--	59.6	46.8	102.0	--	--	--	-42.4	--	- 41
4b	81.4	--	--	--	85.1	--	+3.7	--	+4.5	--
5b	--	48.6	--	66.7	--	--	--	-18.1	---	- 27
Total	502.8	367.7	46.8	603.7***	503.6	6.73	+0.8	- 236	+10.8	- 18
$\bar{X}$	125.7	73.5	46.8	120.7***	125.9	73	+0.2	- 47.2	+2.7	- 36
SD	51.1	21.3	--	88.8***	39.0	--	--	--	--	--
N	4	5	1	5***	4	1	4	5	4	5

* a = trials in April, 1984; b = trials in July 1985.

** Dash indicates opposite uniform group provided data for this trial.

*** Missing Data for second trial. First trial data not included in the analysis (did not recompute SD).

TASK 3

"Remove and Replace M109 Howitzer Breechblock" was performed by two-person crews; one member was experienced and the other was a student. The task was performed from 4 to 8 times each by the 10 crews. Data are presented in Table D-3 (revised from Montgomery, 1987). Most of the initial three trials were performed by crews wearing MOPP 4 (25 out of 28 trials). Examination of the data for the first four trials for the MOPP 4 condition indicates that substantial learning is taking place. The mean time for the MOPP 4 condition for trial 1 was 29.8 minutes, for trial 2, 16.9 minutes, for trial 3, 13 minutes, and for trial 4, 12.1 minutes. Examination of Table D-3 indicates that trial 4 provides the best estimate of the deficit due to MOPP 4. For trial 4, six crews in BDU performed the task with a mean time of 9.6 minutes; four crews performed the task in MOPP 4 with a mean time of 12.1 minutes. This results in an average difference of 2.5 minutes or a 26 percent time decrement between BDU and MOPP 4. Using a regionalized statistical approach, Montgomery (1987) found a 25 percent ± 25 percent decrement.

The data for this task indicate that the teams were able to perform the task about as well in MOPP 4 as in BDU, but the performance in MOPP 4 took about 26 percent longer. Performance improved substantially with repeated practice in MOPP 4, but based on the experimental design, the limited data set, and the lack of equal data sets for each trial for BDU and MOPP 4, the increased efficiency of performing the task as a team and the improvement due to adaptation to MOPP 4 cannot be determined. Some improvement in performance continued between trials 5 and 8 for both the BDU and the MOPP 4 condition.

TASK 4

"Recovery of M60A3 Tank" was performed by four-person crews. The task was performed from 3 to 6 times (9 of 10 crews performed at least 4 trials); the data from Montgomery (1987) are reproduced in Table D-4.

Seven of 10 crews performed the first try in BDU while eight, ten and seven of the crews performed trials 2, 3, and 4 respectively in MOPP 4. It is clear that performance improved with practice, but the experimental design and the lack of data for BDU after the first trial make meaningful comparison between BDU and MOPP 4 impossible to compute.

Table D-3. Time (min) to Remove and Replace M109 Breechblock (from Montgomery, 1987)

Team	Trials							
	1	2	3	4	5	6	7	8
	Battle Dress Uniform (BDU)							
1a*	--*	--	--	9	--	--	--	6
2a	18	--	--	--	--	--	--	7
3a	--	--	--	9	9	--	--	--
4a	--	--	--	13				
5a	--	--	--	10	--	--	10	--
1b	**no	--	--	--	0			
2b	--	--	--	8				
3b	--	15.0	--	--				
4b	--	--	--	8.5	12.0			
5b	20.1							
Total	38	15	0	57.5	2	0	10	13
x̄	19.1	--	--	9.6	10.5	--	--	6.5
SD	--	--	--	1.8	--	--	--	--
N	2	1	0	6	2	0	1	2
	Mission Oriented Protective Posture (MOPP 4)							
1a*	17	20	12.5	--	10	10	7.5	--
2a	--	16.5	14	12	11	9	8	--
3a	30	9	11	--	--	9	10	9
4a	34	29	18	--				
5a	25	15	14	--	18	11	--	
1b	--	21	14.9	10.1				
2b	35	18.1	12.3	--				
3b	--	--	11.8	15.5	10.1			
4b	38	8.4	9.1	--	--			
5b	--	14.9	12.0	10.8	8.4			
Total	179	151.9	129.6	48.4	57.5	37	15.6	9
x̄	29.8	16.9	13	12.1	11.5	9.8	5.2	--
SD	7.7	6.3	2.4	2.4	3.7	1.0	--	--
N	6	9	10	4	5	4	3	1

x̄ = Average
SD = Standard Deviation
N = Number of Cases
* Dash indicates crew wore other uniform
**no = no data

Table D-4. Time (min) to Recover M60A3 Tank (from Montgomery, 1987)

Team	Trials					
	1	2	3	4	5	6
	Battle Dress Uniform (BDU)					
1a*	23.3	--	--			
2a	42.4	--	--	--		
3a	28.1	--	--	--		
4a	13.6	--	--	--		
5a	--	--	--	11.9		
1b	25.6	28.4	--	--	--	
2b	--	--	--	--	8.0	5.4
3b	16.7	--	--	--		
4b	--	--	--	9.5	8.3	
5b	19.1	12.5		--	--	
Total	168.8	30.9	0	21.4	16.3	5.4
$\bar{X}$	24.1	15.4	--	--	--	--
SD	9.5	4.2	--	--	--	--
N	7	2	0	2	2	1
	Mission-Oriented Protective Posture (MOPP 4)					
1a*	--	18.6	13			
2a	--	38.2	29	31		
3a	--	17.0	15	13.6		
4a	--	14	15	14.9		
5a	37	19	19.7	--		
1b	--	--	12.8	10.6	13	
2b	16.4	17.1	10.1	11.8	--	--
3b	--	16.2	13.0	12		
4b	15.5	12.3	8	--	--	
5b	--	--	7.9	7.5	7.8	
Total	68.9	152.4	143.5	101.4	20.8	0
$\bar{X}$	23	19.1	14.4	14.5	--	--
SD	12.2	8.1	6.2	7.6	--	--
N	3	8	10	7	--	0

$\bar{X}$ = Average
SD = Standard Deviation
N = Number of Cases
* Dash indicates crew wore other uniform

TASK 5

"Repair of M60 Machine Gun" was performed by one soldier; 12 subjects performed between 8 and 13 trials. A total of 36 trials were conducted in BDU while 60 trials were conducted in MOPP 4. Thirteen of the 36 trials performed in BDU were conducted during the first two trials. Table D-5 provides the data (reproduced from Montgomery, 1987) for this task.

The mean time to repair the M60 machine gun for trial 1 was smaller for MOPP 4 (11.9, N of 4) than for BDU (14.3, N of 7). For the second trial, however, the mean for BDU is smaller, 7.7 (N = 6) than MOPP 4, 10.1 (N = 5). The performance improvement for BDU vs. MOPP 4 from trial 1 to trial 2 was substantially greater, 14.3 to 7.7 (46 percent change) to 11.9 to 10.1 (15 percent change). Comparison between the two groups is difficult for later trials due to the lack of data for BDU. There is very little performance improvement for the BDU condition from the second through the fifth trials for MOPP 4, but a comparison of the weighted average of these trials 11.5 (N = 30) to the weighted average of the sixth through the ninth trials, 8.8 (N = 22) shows a 23 percent improvement. A weighted average for the first three trials for BDU and MOPP 4 indicates no difference in performance (BDU X = 10.7, N = 16; MOPP 4 X = 10.6, N = 17).

TASK 6

"Repair of M901 Traverse Mechanism" was performed by one soldier. Ten subjects performed at least 4 trials, 4 performed 5 trials, and 1 subject performed 6 trials. The data in Table D-6 are reproduced from Montgomery (1987).

For Task 6, the mean repair times were computed for trials 1-4 without regard to clothing type. The results are shown in Figure D-1.

As can be seen by the results in Figure D-1, the mean repair times showed a monotonic decrease from trials 1-4 regardless of clothing type. For trials 2 and 3, all subjects were dressed in MOPP 4; for trials 1 and 4, half of the subjects were dressed in BDU and half in MOPP 4. The dress type for all subjects was changed from Trial 1 for Trial 4.

Table D-5. Time (min) Required to Repair M60 Machine Gun When in BDU or in MOPP 4 (from Montgomery, 1987)

Team	Trials												
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Battle Dress Uniform (BDU)												
1a*	16	7	--	--	--	--	--	--					
2a	17	6	--	--	--	--	5	6	--	--			
3a	--	--	--	--	--	--	--	6.2	5	5.8	5.8	5	--
4a	5.4	5.1	4.6	5	--	--	--	--	--	3	3.2	--	3.1
5a	--	--	--	--	--	--	--	--	--	5	4.3	4.3	3.3
1b	22.9	--	10.4	--	--	--	--	--	--	6.5			
2b	--	7.4	--	--	--	--	--	--	5.0	4.4	--		
3b	8.5	5.1	--	--	--	4.6							
4b	--	--	--	--	4.8	4.2							
5b	16.5	15.6	--	--	--								
6b	13.8	--	9.2										
Total	100.1	46.2	24.2	5.0	4.8	8.8	5	12.2	10.0	19.8	13.3	9.3	6.4
x̄	14.3	7.7	8.1	5.0	4.8	4.4	5.0	6.1	5.0	4.9	4.5	4.6	3.2
SD	5.8	4.0	3.1	--	--	0.3	--	0.1	--	1.1	1.3	0.5	0.1
N	7	6	3	1	1	2	1	2	2	4	3	2	2
	Mission-Oriented Protective Posture (MOPP 4)												
1a*	--	--	7	7	11	7	6	4					
2a	--	--	12	9	17	11	--	--	13	11.8			
3a	9.2	11.2	14.3	9.2	10.1	7.0	8.8	--	--	9.0	--	--	
4a	--	--	--	--	6	8	6.8	6	6.7	--	--	5.8	--
5a	14	7	9	10.8	7.4	6.8	7.1	11	5	--	--	--	--
1b	--	9.3	--	13.4	10.0	8.9	16.8	11.8	7.4	--			--
2b	13.9	--	8.3	13.4	17.8	11.9	16.4	5.5	--	--	5.3		
3b	--	--	10.6	22.0	6.9	--							
4b	10.5	7.6	11.2	14.7	--	--							
5b	--	--	10.4	11.6	13.7								
6b	--	15.4	--										
Total	47	50.5	82.8	111.1	99.9	60.6	61.9	38.3	32.1	20.8	5.3	5.8	--
x̄	11.9	10.1	10.4	12.5	11.1	8.7	10.3	7.7	8.0	10.4	5.3	5.8	--
SD	2.4	3.4	2.3	4.6	4.3	2.1	5.0	3.5	3.5	2.0	--	--	--
N	4	5	8	8	9	7	6	5	4	2	1	1	--
MOPP 4 Less BDU	-2.4	2.4	2.3	7.5	6.3	4.3	5.3	1.6	3.0	5.5	0.8	1.2	--
Change as a % of BDU	-17	31	28	150	131	98	106	28	60	112	18	26	--

$\bar{x}$ = Average
SD = Standard Deviation
N = Number of Cases
Note: A dash indicates that data for this try were obtained by the crew attired in the alternate uniform.

Table D-6. Time (min) Required to Repair M901 Traverse Mechanism When in BDU or in MOPP 4 (from Montgomery, 1987)

Team	Trials					
	1	2	3	4	5	6
	Battle Dress Uniform (BDU)					
1a	21	--	--	--		
2a	--*	--	--	(37)	29	
3a	25	--	--	--	--	12
4a	--	--	--	16		
5a	--	--	--	13		
1b	77.5	--	--	--	25.5	--
2b	--	--	--	21.9		
3b	57.1	--	--	--	--	
4b	--	--	--	18.4		
5b	52.6	--	--	--		
Total	233.2	--	--	106.3	54.5	12
$\bar{X}$	46.6	--	--	21.3	27.3	--
SD	23.6	--	--	3.7	--	--
N	5	0	0	4	2	1
	Mission-Oriented Protective Posture (MOPP 4)					
1a	--	24	50	25		
2a	80	58	32	--	--	
3a	--	48	31	29	21	--
4a	40	31	29	--		
5a	78	44	31	--	--	
1b	--	86.0	38.5	37.7		
2b	93.5	40.2	45.5	--		--
3b	--	55.6	43.7	46.6	30.5	
4b	46.0	33.5	26.0	--		
5b	--	42.4	(36.4)	30.5		
Total	337.5	462.7	326.7	168.8	51.5	--
$\bar{X}$	67.5	46.3	36.3	33.8	25.8	--
SD	23.2	17.5	8.4	8.5	--	--
N	5	10	9	5	2	--

$\bar{X}$ = Average
SD = Standard Deviation
N = Number of Cases
Note: A dash indicates that data for this try were obtained by the crew attired in the alternate uniform (BDU versus MOPP 4).
( ) = Values in parentheses are interpolated from row and column means.

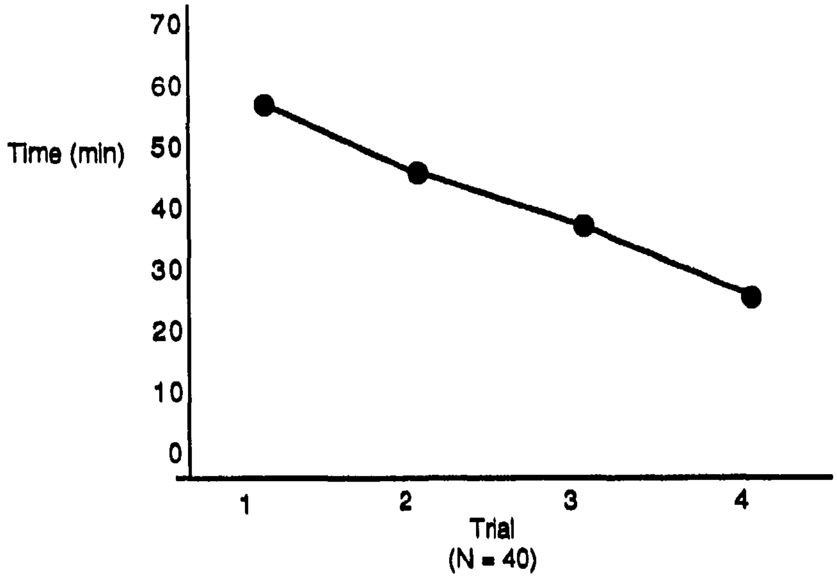

Figure D-1. Time (min) by Trials to Repair M901 Traverse Mechanism Without Regard to Clothing Type

Figure D-2 clearly indicates the effect of wearing MOPP 4. For the first trial, the BDU first group (N = 5) required a mean of 46.6 minutes to complete the repair, while the MOPP 4 first group required 67.5 seconds (a difference of 20.9 minutes or a decrement of 31 percent for the MOPP 4 first group). For trial 4 with the clothing conditions changed for both groups, the BDU first group (MOPP 4 condition) required 33.8 minutes while the MOPP 4 first group (BDU condition) required only 21.3 minutes (a difference of 12.5 minutes or decrement of 37.3 percent for the MOPP 4 condition). A comparison of the means for trial 2 and trial 3, during which subjects were in MOPP 4 (trial 2 X = 46.3, N = 10, trial 3 X = 36.3, N = 9) indicates a 22 percent improvement in performance. This improvement is a combination of learning to accomplish the task and learning to accomplish the task in MOPP 4. Unfortunately the results of these two effects are confounded.

Using regionalized statistics, Montgomery (1987) found a 50 percent ± 30 percent *decrement* for the MOPP 4 condition.

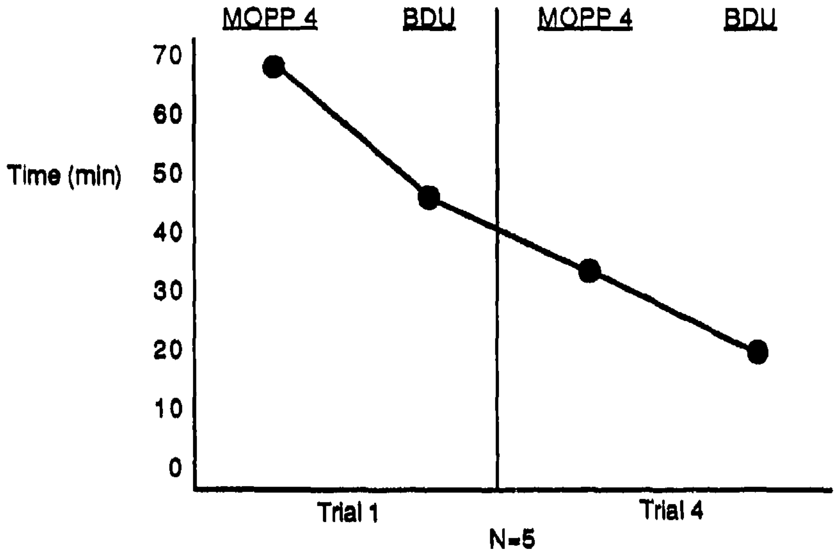

Figure D-2. Comparison of BDU and MOPP 4 for Trials 1 and 4

TASK 7

"Repair of FADAC Printed Circuit Board" was performed by one soldier; a total 5 subjects performed the task both in BDU and MOPP 4. All subjects performed at least 6 trials; of those a total of 5 trials were performed in BDU and 24 trials were performed in MOPP 4. The data in Table D-7 are reproduced from Montgomery (1987).

The performance improvement between the second and the sixth trial for MOPP 4 was substantial. The mean time for trial 2 was 32 min (N = 5) and for trial 6 the mean time was 22 min (N = 5), an improvement of 31 percent. The lack of data for the BDU condition prevents meaningful comparisons.

Table D-7. Time (min) Required to Repair FADAC Printed Circuit Board When in BDU or in MOPP 4 (from Montgomery, 1987)

Team	Trials									
	1	2	3	4	5	6	7	8	9	10
	Battle Dress Uniform (BDU)									
1a	(21)	--	20	--	--	--				
2a	35	--	--	--	--	--	11	--	--	6
3a	--	--	--	23	--	--				
4a	29	--	--	--	--	--	21			
5a	--	--	--	7	--	--	6.9	17	--	--
Mean	32	(26)	20	15	(14)	(14)	13	17	--	6
Deviation	4.2	--	--	11.3	--	--	7.2	--	--	--
N	2	0	1	2	0	0	3	1	0	1
	Mission-Oriented Protective Posture (MOPP 4)									
1a	--	36	--	28	19	21				
2a	--	20	22	19	16	23	--	12	11	--
3a	55	68	34	--	25	29				
4a	--	19	20	22	24	22.8	--			
5a	32.3	19	24	--	23	15	--	--	14	12
Mean	44	32	25	23	21	22	(16)	12	12	12
Deviation	16.1	21.2	6.2	4.6	3.8	5.0	--	--	2.1	--
N	2	5	4	3	5	5	0	1	2	1
$\bar{X}$ MOPP 4 Less $\bar{X}$ BDU	12	6	5	8	7	8	3	–5	--	6
Change as a % of BDU	37	23	25	53	50	57	23	–29	--	100

Note: Dash indicates that data for this try were obtained by the crew attired in the alternate uniform (BDU versus MOPP 4).

( ) = Values in parentheses are interpolated.